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Assessment of Herbicide Best Management Practices: Status of Our Knowledge of BMP Effectiveness

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Final Report

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EXECUTIVE SUMMARY

The adequacy of herbicide best management practices (BMPs) for protecting water quality in forest and rangelands is incompletely known. A variety of BMPs are routinely employed to help assure that water quality is not degraded. Among others, BMPs limiting herbicide application under various meteorological conditions, mandating buffers adjacent to water bodies, and specifying methods to reduce drift of liquid herbicide onto sensitive areas are widely implemented.

The actual scope of implementation is also incompletely known, although all states and federal agencies incorporate BMPs, or their functional equivalents, into herbicide application programs. In this report implementation is operationally defined as doing what we said we'd do to protect water quality. Effectiveness is how well water quality is protected by implementing the BMPs.

This report compiles information on herbicide BMP implementation and effectiveness in forest and rangelands. To parallel the more common water quality standards and criteria applicable to herbicide applications, the focus of this investigation is on surface waters. Specific objectives are to—

- Assess the scope of herbicide BMP implementation in forest and rangelands for the protection of surface water quality
- Summarize herbicide BMP effectiveness monitoring and research studies, including procedures for determining riparian buffer widths
- Summarize herbicide BMP effectiveness monitoring procedures and results of effectiveness studies or monitoring
- Identify information needs
- Draft a stand-alone primer summarizing the results of the project.

Literature review, interviews with experts in academia, government research, private industry, and herbicide application, water quality monitoring, and regulation are two sources of information used in this project. Results from questionnaires on BMP implementation and effectiveness are a third information source. Sixty individuals were

interviewed and thirteen questionnaires were completed. Journal articles as well as a variety of limited circulation reports from various institutions were reviewed.

The dynamics of herbicide movement from initial point of treatment, as a liquid, granule or pellet, applied by any of a variety of ground-based techniques or aerially, is complex. Each herbicide's water solubility, adsorption, and volatility contribute to its ultimate degradation in soil, water or air, or incorporation into biota. The timing, frequency, rate, and method of application critically control herbicide dynamics. For aerial treatments in particular, droplet size and subsequent drift potential relate directly to the effectiveness of BMPs, particularly buffers. Once on the ground, soil properties, weather and climate, groundwater attributes, and geologic conditions hasten, slow or terminate herbicide movement to surface waters. The complexity of these biogeochemical processes makes site-specific and herbicide-specific estimation of herbicide fate problematic. And modeling is currently inadequate to quantitatively predict the disposition of herbicide into surface waters or the effectiveness of herbicide BMPs.

Formal documentation of rates of herbicide BMP implementation is primarily undertaken at the state level, mostly by states in the southern US. On-site examination, weeks or months after treatment, is the typical method for implementation assessment, with questions typically posed for yes/no answers (e.g., "Kept aerial/mist-blown pesticides out of Primary [streamside] Zone?"). Implementation rates at and above 90% are often cited. Drift or direct spray of herbicide onto live water is cited in the state reports, the interviews and the questionnaires as the most common BMP implementation failing.

BMP effectiveness is partially a function of the water quality criteria in place at a given locality. BMPs that help protect drinking water quality (for instance by keeping herbicide concentrations below a Health Advisory criteria) may not be effective with respect to a water quality standard that allows no quantifiable detection of any herbicide. Opinions on BMP effectiveness range from "yes" to "no" (commonly the 0-detectability case), to "don't know" when monitoring results are not available to assess effectiveness.

Almost no documentation was identified assessing the effectiveness of specific BMPs. Research studies on the fate and transport of herbicides and operational monitoring of water quality by land management agency are relatively common and thousands of water samples have been collected and analyzed for herbicide content. These efforts seldom mention BMPs other than buffers, and the rationale for buffer width determination is seldom given. Effectiveness is determined by water column chemistry measurements. If sample concentrations are below relevant water quality criteria, BMPs are implicitly presumed to be implemented and effective. Specific BMPs are mentioned only in retrospective analyses aimed at determining the cause of any water quality problems. Because most monitoring and research studies measure relatively low concentrations of herbicides in surface waters of forest and rangelands, specific BMPs are seldom addressed.

The monitoring studies and fate and transport research often quantify low, but detectable levels of herbicides concurrent with or immediately after (1) herbicide application and (2) the first or the first few rain-induced runoff events after application. These two situations for herbicide detection illustrate potential failings in BMP implementation.

Herbicide detection in surface water concurrent with, or soon after application, is due to direct over-spray onto live water, or off-target drift; no other mechanisms can move herbicide quickly enough to be observed in water at the time of application. Prohibition on herbicide deposition directly onto surface water is a common forest practice rule, label directive or water quality standard, and BMPs directed at prohibiting deposition onto live water are common.

Two factors are cited as contributing to live-water deposition. First, identification of surface water is problematic where vegetation canopies are dense, particularly when surface water identification is from aircraft reconnaissance rather than walking a stream channel. Known surface waters are typically buffered, which reduces the likelihood of direct deposition onto surface waters. If live water isn't identified, it isn't buffered and overspray is likely. A related problem is change in the geographical location of surface water between its initial mapping and herbicide treatment. Mapping in the autumn, during relatively dry conditions may minimize the extent of surface water compared to spring when winter rains and snowfall expand the surface area of water bodies. Buffers mapped under dry conditions may be too narrow at the time of herbicide application. This is accentuated if timber harvest occurs between mapping and treatment. Tree removal will reduce evapotranspiration and consequent increase stream flow.

Second, with aerial application of liquid herbicide, the common practice of "swath displacement" attempts to account for wind-induced shifting of the cloud of herbicide spray droplets. Imprecise swath displacement can result in drift of spray droplets onto surface water.

Elevated herbicide concentrations associated with post-treatment rain storms result when ephemeral or intermittent stream channels that were dry at the time of application (and therefore were not buffered) channel herbicide-laden runoff to perennial streams. Buffering intermittent and ephemeral channels is a fix to this problem, although doing so could put appreciable acreages of land off limits to herbicide application, particularly in watersheds with high drainage densities.

Other situations that influence BMP implementation and effectiveness by elevating herbicide concentrations in surface waters are—

- Geologic conditions favoring rapid sub-surface water/herbicide flow to surface waters. Macropores or extensive near-surface bedrock or impermeable layers foster the rapid flows. Mapping and knowledge of groundwater dynamics and geologic conditions could be better incorporated into BMPs to address this potentiality.
- Obstacles (e.g., snags or localized topographic high points) in the treatment zone near buffers that cause aircraft to fly higher than appropriate for minimizing draft.

Better mapping of topography and vegetation near buffer boundaries could be incorporated into BMPs to address this potentiality.

- Watersheds with tributaries entering mainstem channels at right angles, particularly where drainage density is already high. This scenario causes problems because flightpaths in aerial application should parallel buffer and stream boundaries, otherwise the risk is great that drift or direct overspray onto surface water will occur. With high drainage density and right-angle tributaries, room will often be insufficient to fly parallel to the buffers. For these types of situations, ground application may be the best approach to assure water quality protection.
- Herbicide application in riparian areas for noxious weed control. This type of high-risk treatment can negate much of the benefit derived from riparian buffers for reducing surface water impacts.
- The use of aerial versus ground application techniques. Risks of impacts to water quality are much greater for aerial treatments.

Relatively little information was offered in the interviews and questionnaire responses, or found in the literature review, on knowledge gaps. Three topics were mentioned several times:

- Comprehensive, validated models addressing the full suite of pathways for chemical movement into water bodies (e.g., drift, runoff, sub-surface flow).
- Sub-lethal and other biological effects of herbicides, especially as they influence buffer width determinations.
- Potential improvements in herbicide application equipment and technologies (e.g., the efficacy of half-booms) that could provide better control for aerial treatments.
- Improved methods for systematically determining effective buffer widths.

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INTRODUCTION

Herbicides can be valuable tools to help manage noxious weeds and to accomplish other forestry and rangeland management objectives. The toxicity that makes herbs effective can have side effects on beneficial uses of water (e.g., on aquatic biota and potentially human health). State and local water quality standards and criteria address these potentialities. Public perception of the effects of herbicide use on public lands is generally cautionary, and numerous mitigations are often employed to assure herbicide use does not degrade water quality. Uncertainty about the implementation and effectiveness of the mitigations (Best Management Practices), in combination with uncertainty about ecological effects of herbicides and their formulations (mixtures of active and inert ingredients and impurities) prompts continuing public concerns. The broad objective of this investigation is the compilation of information on the implementation and effectiveness of herbicide Best Management Practices (BMPs) for protecting water quality in forest and rangelands, with a focus on herbicide application for control of noxious weeds and reforestation. The need to assess BMP effectiveness is recognized by federal regulatory and land management agencies (Palmer 2002) and potential effects and mitigation of herbicide use are routinely described in environmental documentation authored by federal agencies (e.g., USDA Forest Service 2003a, USDI BLM 2003).

Herbicides differ in their toxicity and other chemical properties and consequently also in how they are transported and degraded in air, soil and water. This investigation focuses on herbicides in general use by the USDI BLM and the USDA Forest Service, specifically 2,4-D, clopyralid, dicamba, glyphosate, hexazinone, imazapic, imazapyr, metsulfuron-methyl, picloram, sulfometuron-methyl and triclopyr, but includes other herbicides peripherally when information on the primary herbicides is not available.

Herbicides can reach water bodies either directly through aerial or ground application, or indirectly through surface runoff or subsurface flow. Aquatic organisms can be affected by direct exposure to toxic compounds in herbicides in water or through ingestion. Indirect effects may stem from increased organic matter inputs to water bodies and other impacts to riparian vegetation. These secondary effects may alter physical properties of streams, by increasing water temperature and sedimentation, due to loss of riparian vegetation. Direct effects on water quality are the focus of this investigation. Biological and secondary physical effects are not dealt with. The emphasis instead is on the usefulness of practices aimed at minimizing herbicide entrainment into water bodies.

OBJECTIVES AND METHODS

Specific objectives are to—

- Assess the scope of herbicide BMP implementation in forest and rangelands
- Summarize herbicide BMP effectiveness monitoring and research studies, including procedures for determining riparian buffer widths
- Summarize herbicide BMP effectiveness monitoring procedures and results of effectiveness studies or monitoring
- Identify information needs
- Draft a stand-alone primer summarizing the results of the project.

Implementation is defined as doing what we said we'd do to protect water quality. Effectiveness is how well water quality is protected by implementing the BMPs.

Three primary sources of information were used: (1) interviews with individuals familiar with herbicide use for noxious weed control and reforestation, (2) literature review, and (3) responses to a written questionnaire on herbicide application and BMP implementation and effectiveness.

Interviewees were from a broad spectrum of players in the herbicide field. Opinions, documents and data were gathered from on-the-ground herbicide applicators--typically from federal land management agencies, state and federal government staff and state forestry departments overseeing herbicide treatments, staff of state and federal government regulatory agencies (e.g., USDI FWS and USDC NOAA Fisheries, Lahontan Regional Water Quality Control Board--California), academic and government researchers of herbicide fate and transport, and industry representatives. Over 60 individuals were contacted. Detailed transcriptions of their comments are in Appendix A. Any mis-representation of interviewee comments or questionnaire responses is the responsibility of the author of this report.

A broad variety of documents were reviewed. Reports on forest and rangeland BMPs are the most directly useful. Investigations on related herbicide uses, for instance in agriculture and powerline right-of-way applications, were reviewed to assure as broad a spectrum of relevant information as possible. Publications from the peer-reviewed literature, as well as many "grey" literature, limited circulation agency reports, such as monitoring plans or reports, Biological Assessments or Biological Opinions, and court declarations, were obtained and searched for relevant information. Both traditional, library-based searches and Internet-based searches were undertaken.

Questionnaires focusing on the details of herbicide BMP application, and implementation and effectiveness monitoring were sent to 30 individuals. Reminders to individuals were sent out to attempt to recoup the greatest number of completed surveys possible. The reminders were communicated electronically and included an abbreviated set of seven questions in hopes that hard-pressed individuals could at least address the abbreviated form of the survey. Completed surveys were returned slowly and responses were received from 13 individuals. Some individuals preferred, largely to save time, to discuss

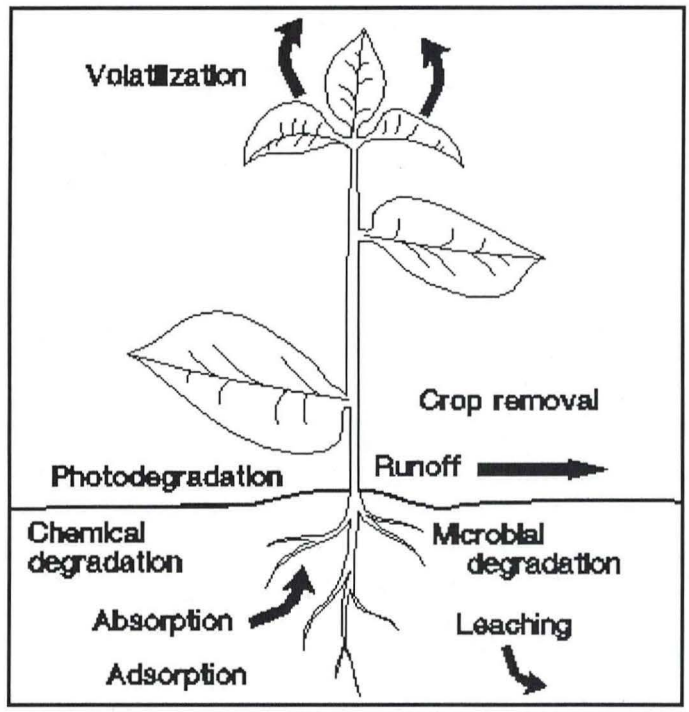
the survey questions by phone. Input from these individuals was incorporated into the results from the interviews and is not directly discussed with respect to the questionnaire responses.

The results of this evaluation are limited to the literature reviewed and the individuals spoken to. Comprehensive attempts were made to both obtain relevant literature and talk to qualified individuals. Appendix B documents the questionnaires and the responses received. Appendix C summarizes the questionnaire responses.

HERBICIDE DYNAMICS AND WATER QUALITY

A herbicide can move through a variety of pathways from its initial application until absorption in plants, complete degradation in soil, volatilization in air, or transport into water (Figure 1). The dominance of any particular pathway, or set of pathways depends on a multiple of factors, including application method, timing and amount, herbicide properties, soil properties, site conditions, and management practices. Application methods commonly involve the movement of herbicide through air, commonly as a liquid spray, but also as granules and pellets. Airborne spray is most susceptible to off-target movement, with potential implications to water quality.

Figure 1. Schematic herbicide movement and degradation pathways (from Mahler et al. 2002).



Once on the ground or plant surface, herbicide fate is controlled by numerous, simultaneous biological, physical and chemical processes. These processes address the transformation, transfer and transport of herbicides and include those specific to each herbicide and those specific to the treatment location. Herbicides may be taken up by plants, ingested by animals, insects, worms or microorganisms in the soil, move downward in the soil and either adhere to soil particles or dissolve—to be moved in soil or ground water, degraded into less (or more) toxic compounds, carried away in runoff water on the soil surface, or transported while attached to eroding sediment. Complexity increases quickly because of the large number of chemicals, each with different characteristics, in combination with a myriad of different soil, vegetation and geologic characteristics.

This chapter is not meant to address the intricacies of all possible pathways. The intent is to (1) outline the major biogeochemical processes influencing the entry into water bodies of herbicides applied on forest and rangelands, and (2) provide an understanding of how decisions made in operational herbicide treatments relate to decisions on best management practices. The sequence of topics follows the typical sequence of operational herbicide usage, from application, through soil and sub-surface processes and eventually to surface water. An underlining premise is the dynamic between improved treatment efficiency and the need to protect environmental resources. Numerous choices are routinely made, for instance about type of herbicide, application method and timing, or mitigation implementation to address this "trade-off".

Herbicides

Herbicides are formulated chemicals that kill all or part of target plants. Broad-spectrum herbicides are effective against all plants or specific classes of plants (e.g., just grass-like plants or just woody plants). Narrow-spectrum herbicides are aimed at specific kinds of target plants. Herbicides are formulated primarily into liquids, granules or pellets.

Herbicides affect plants either by inhibiting or interfering with plant biochemical processes. "Soil active" herbicides enter plants through their root systems; "foliar active" chemicals are taken up by target plants through their steams and leaves.

Non-active, or "inert" chemical components are additives in herbicides aimed at improving herbicide effectiveness, for instance, as surfactants that enhance herbicide spreading, wetting and retention on leaf surfaces and improve penetrability of the plant cuticle. Other inerts components are impurities from herbicide processing. Additives do not directly cause herbicidal effects but they may be toxic themselves.

The major property herbicides have in common is their broad function as tools for plant control. Herbicides exhibit vastly different persistency, mobility, and toxicity. Four chemical properties critical to the ultimate disposition of herbicides in the environment are the chemical's water solubility, soil adsorption, volatility and degradation or persistence.

Water Solubility

The tendency of a herbicide to dissolve in water affects the ability and magnitude of the chemical's movement in water. As water seeps downward through soil, it carries with it water-soluble chemicals. This process is called leaching. Water solubility greater than 30 milligrams per liter (or parts per million) can be considered a "flag" for potential to leach. Highly soluble herbicides have a tendency to be carried in surface runoff and to be leached from the soil to groundwater; hydrophobic herbicides are unlikely to move in a dissolved state but may be adsorbed to suspended particulate or colloidal materials and move as erosion (Alabama Cooperative Extension 1999, Zaber 2003).

Adsorption

Adsorption refers to the attraction between a chemical and soil particles. Herbicide molecules that are positively charged, for example, are attracted to, and can bind with negatively charged clay particles. Many herbicides do not leach because they are adsorbed, or tightly held, by soil particles. Herbicides that are weakly adsorbed will leach in varying degrees depending on their solubility. Even strongly adsorbed herbicides can be carried with eroded soil particles in surface runoff (Alabama Cooperative Extension 1999). In general, but not exclusively, herbicide adsorption relates inversely to herbicide solubility in water. Highly soluble herbicides are weakly adsorbed and pose a greater threat of groundwater contamination (Mahler et al. 2002). Adsorption can be quantified and several indices have been developed to rate the adsorptivity of herbicides.

Volatility

The tendency of a herbicide to become a gas, similar to the evaporation of water, affects its loss to the atmosphere by volatilization. If a highly volatile herbicide is not very water soluble, it is likely to be lost to the atmosphere and less will be available for leaching or movement in runoff. Nevertheless, highly volatile herbicides may become groundwater contaminants if they are highly soluble in water. Although volatilization of some herbicides can critically affect their potential for off-target movement (Birchfield 2003), for most herbicides, loss through volatilization is insignificant compared with leaching or surface losses. Volatile herbicides may cause water contamination or other problems from aerial drift. Environmental conditions such as temperature, humidity, and wind speed affect volatilization losses. Special surfactants or carriers can be used to reduce volatilization losses (Alabama Cooperative Extension 1999).

Degradation

A herbicide's rate of degradation (persistence) in soil and water critically affects leaching and runoff pathways to surface waters. Herbicides are degraded, or broken down into other chemical forms, by sunlight (photodecomposition), by ingestion by worms, animals, insects or microorganisms in the soil, and by a variety of chemical and physical reactions (Mahler et al. 2002, Alabama Cooperative Extension 1999). Typically, chemical reactions only partially deactivate herbicides whereas soil microorganisms can completely break down many herbicides to carbon dioxide, water and other inorganic constituents. Some herbicides produce intermediate substances called metabolites as they degrade. The biological activity of these substances may or may not have environmental significance. Microbes decrease rapidly below the root zone, so herbicides leached below this depth are less likely to be microbially degraded (Mahler et al. 2002). The longer the compound lasts before it is broken down (e.g., the longer it persists) the longer it is subject to leaching and runoff.

Persistence in soil varies greatly by herbicide. Some are relatively stable under nearly all environmental conditions. However, many herbicides do degrade in response to environmental factors. Because herbicides applied for forestry and rangeland purposes

often enter soil, aerobic (oxygen rich) soil conditions are the primary environment for chemical degradation in soil (Birchfield 2003). Soil temperature is often a major driver of degradation rate, with temperature positively correlated with degradation; the higher the temperature the quicker the decomposition.

Persistence is commonly indexed by "half-life", the amount of time required for a herbicide in soil to degrade to one-half the activity level it had at application (i.e., for a herbicide with a half-life of 30 days, 50 percent of the herbicide will have degraded after 30 days). Herbicides have been classified by half-life as—

- Non-persistent (half-life less than 30 days).
- Moderately persistent (half-life of 30-100 days).
- Persistent (half-life greater than 100 days) (Mahler et al. 2002).

Application Method

A central goal is keeping herbicides out of streams, lakes and other water bodies. Applying herbicides distant from water bodies is one basic method of achieving this goal. However, some objectives of herbicide use—control of noxious plants in riparian zones—require treatment near water, thereby complicating a simple "solution" to herbicide water quality issues. Even for riparian applications, locational control of chemical deposition onto target plants, or the soil, is an underlying objective of any herbicide application.

Herbicides are applied operationally to forest and rangelands by air or ground techniques, typically as liquid, liquid spray, granules, or pellets. Physical attributes of each technique are shared by all herbicides. Spray droplet size spectrum, for instance, influences the potential for drift to off-target locations of all herbicides approximately equally because droplet dynamics are not herbicide-specific. Herbicide-specific properties like water solubility and soil adsorptivity come into play after the herbicide is deposited on soil or vegetation.

Aerial herbicide application in forest and rangelands is primarily by liquid spray from fixed wing aircraft, or more commonly helicopters. Ground application can also use liquid spray applied from hand-held spray guns attached to backpacks, conventional vehicles or ATVs, and spot gun sprayers mounted on vehicles or ATVs. Spray applications can drift off target. This off-target drift is a major avenue for herbicide entering surface waters and many BMPs are directed toward minimizing drift.

Other ground application techniques include hand spreading of granular formulations of herbicide, and a variety of techniques hand-applied to individual target plants (e.g., wicking, wiping, dripping, "thin lining", "cut and daub", "painting", "hack and squirt" or direct stem injection (USDA Forest Service 2003a)). From a water quality perspective, the closer the chemical is sprayed, deposited or injected onto or into the target plant or soil the better, and the labor intensive thin lining, cut and daub, hack and squirt or related techniques lower the risk of water quality degradation.

Aerial application is typically less expensive than ground application, particularly the labor-intensive treatments of individual plants. Because "drift" is common to both aerial and ground treatments, and because off-target drift is a primary cause of water quality problems, drift is discussed below at some detail.

Drift and Droplet Size

The US EPA (1999) defines pesticide spray drift as "the physical movement of a pesticide through air at the time of application or soon thereafter, to any site other than that intended for application (often referred to as off-target)". A more comprehensive definition given by Giles (2003) is "the physical movement of pesticide droplets, particles, or gas-phase chemicals away from the application site both during and after a pesticide application." This second definition goes beyond spray droplets to include particles and droplets volatizing after application. "Secondary drift", as the volatilization of chemicals from plants and soils (Giles 2003) or the entrainment of soil-bound particles by the wind (Birchfield 2003) can also degrade water quality.

Numerous spraydrift field trails, wind tunnel experiments, and computer models show that droplet size is an important parameter affecting the distance of off-target spray drift. The objective is to deposit herbicide spray droplets only onto target plants and soil in a manner that minimizes environmental problems. For herbicides applied as liquid sprays, the droplet size spectrum that is used in application can vary greatly. Pre-emergent herbicides applied before the emergence of noxious plants are typically applied onto bare ground in coarse sprays that have a relatively low drift potential. In other applications, full target coverage, which is optimized with small droplets that more uniformly coat target plants or soil, is desired although small droplets tend to disperse greater distances in air and have a higher likelihood of moving off-target and entering water. Although coarse sprays are the safest application from a water quality perspective, trade-offs occur because coarser sprays may not adequately cover target plants and consequently higher application rates may be needed (with coarser sprays) to achieve project objectives.

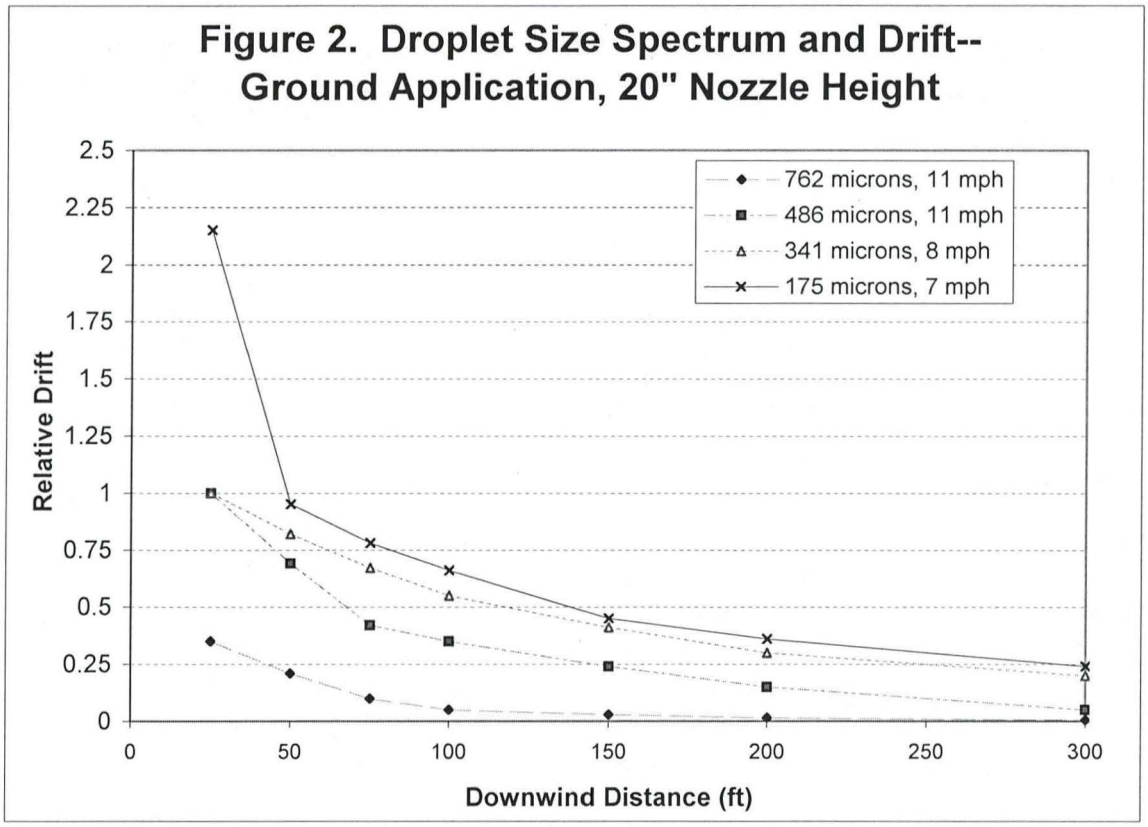
Drift becomes more likely when there is insufficient kinetic energy for droplet transport and impaction, and long travel time between the target and the location of droplet release. Droplet kinetic energy is directly related to droplet size; smaller droplets have less energy. Fine sprays stay aloft much longer than coarser sprays, allowing dispersal (drift) to much greater distances. Using the AgDRIFT model for aerial applications, moving from a relatively coarse spray to a relatively fine agricultural spray, and holding all other inputs constant, results in more than a six-fold increase in deposition at 100' downwind from the edge of the target area (Birchfield 2003). Agricultural field tests show similar results, with coarse sprays associated with decidedly less drift, even at higher wind speeds than fine sprays (Figure 2, after Spray Drift Task Force 1997). As an example of wind and droplet size effects, in still air, a droplet of herbicide the size of 100 microns (mist-size) takes 11 seconds to fall 10 feet. The same size droplet at a height of 10 feet travels 13.4 feet horizontally in a 1 mph wind, and 77 feet at 5 mph wind (USDC NOAA 2002b).

The occurrence and magnitude of drift respond to both environmental conditions and mechanical properties of the treatment equipment and method. Travel time largely equates to application height, and the higher the spray is released the higher the drift potential (Birchfield 2003). Particularly for aerial treatment, whenever the aircraft flies higher, the chance of drift increases, as air turbulence, either from wind or associated with application method (e.g., spray nozzle orientation), accentuates drift. Turbulence can also be increased by (1) increased aircraft speed, (2) higher operating pressure of the spray equipment, and (3) longer application "booms". (Spray is emitted from (near) horizontal "booms" extended out from each side of the aircraft. The booms create turbulence and spray droplets are affected by the turbulence proportional to boom length. The longer the boom the greater the turbulence and consequent spray drift.)

Spray nozzle size and orientation critically affect drift potential. Nozzle size determines the droplet size spectrum. Nozzle orientation relates to potential wind shear effects on droplets. Shearing is typically directly correlated to droplet size spectrum; the greater the shearing the smaller the mean droplet diameter. Rashin and Graber (1993) suggested using "hollow-cone" nozzles in a jet spray configuration oriented straight back toward the tail of the aircraft.

In summary, off-target drift from aerial application is mitigated by—

- Applying the coarsest droplet size spectrum that provides sufficient coverage and pest control.
- Adjusting the spray swath (compensating the aircraft flight path to account for crosswind that would otherwise push the spray droplets off-target).
- Flying parallel to buffer borders and as low and as slowly as safety considerations allow.
- Using low-pressure spray equipment.
- Orienting spray nozzles to face the tail of the aircraft.
- Including non-toxic drift-control agents in the spray formulation.
- Applying herbicides when wind speeds are low, relative humidity is high and the wind blows away from sensitive areas.
- Using the shortest practical applicator boom length (Rashin and Graber 1993, Birchfield 2003, Spray Drift Task Force 1997).



Application Timing and Rate

The timing of herbicide treatments relates to water quality primarily with respect to the precipitation regime of the site and the persistence of the herbicide. If the chemical is applied when runoff is most likely to occur (e.g., during a rainy season), herbicide levels in runoff will likely increase, particularly for moderate or long-lived herbicides. If herbicides are applied during drier seasons, chemical concentrations in runoff would theoretically be lower because the herbicide will have more time to decompose prior to a runoff-generating rainfall event (Birchfield 2003). Leaching potential is also elevated if herbicide is applied during a rainy season, when conditions favor leaching (Alabama Cooperative Extension 1999).

Application rate, the amount of herbicide active ingredient applied per unit area, is generally expected to directly correlate with herbicide concentrations in runoff and spray drift; the greater the application rate, the greater the chance that the herbicide will reach surface water. Application rates can vary considerably among herbicides and even for a single herbicide, depending upon factors including the target pest, site-specific conditions and environmental considerations (Birchfield 2003). Over time, as understanding of the effects of specific herbicides has increased, application rates have generally decreased, with a consequence amelioration in environmental consequences (Michael 2003).

Soil Properties

Site-specific soil properties primarily affect movement of herbicide as surface runoff, or through near sub-surface or deeper groundwater pathways. Soil permeability and organic matter are important as are the presence of wormholes, root channels or other macropore conduits through soil that can hasten sub-surface water-borne herbicide movement.

Permeability

Soil permeability measures the rapidity of water movement downward through a soil. Soil structure and texture control permeability. The relative proportions of sand, silt, and clay determine soil texture. Texture affects movement of water through soil (infiltration) and, therefore, movement of dissolved chemicals such as herbicides. The sandier the soil, the faster the rate of movement and the greater the chance of a herbicide reaching groundwater. Coarse-textured sands and gravels have relatively high infiltration capacities, and water percolates through these soils rather than running off over the soil surface or being adsorbed to soil particles. Coarse-textured soils generally have high potential for leaching of herbicides to groundwater but low potential for surface loss to water bodies. Fine-textured soils such as clays and clay loams usually have low infiltration capacities, and water tends to run off rather than to percolate. Soils with more clay and organic matter also have more surface area for adsorption of herbicides and higher populations of microorganisms to break down herbicides. Therefore, fine-textured soils have relatively low potential for leaching of herbicides to groundwater and high potential for herbicide surface loss (Alabama Cooperative Extension 1999, Mahler et al. 2002).

Soil structure reflects how individual soil particles clump or bind together. Single grain structure is common in sandy soils. Blocky, prismatic and platy are other common soil structures. Structure affects soil pore space, and therefore the ability for water to move through the soil. Dense structures have less pore space than single grain structured sands, another reason why herbicides can move more quickly through sandy soils than clay soils (Mahler et al. 2002).

Organic Matter

Many herbicides are adsorbed by soil organic matter; consequently herbicide movement in soil and potential sub-surface water contamination are elevated in soils with low organic matter contents (Mahler et al. 2002). Soil organic matter also typically holds more water than other soil components, thereby increasing the soil's ability to hold dissolved herbicides in the root zones where plants can access them. Organic matter usually also supports much of the microorganism population in a soil, thereby increasing herbicide degradation rates in comparison to soils with less organic matter (Alabama Cooperative Extension 1999, Mahler et al. 2002, USDC NOAA 2003d).

Weather and Climate

Both longer-term climatic patterns and short-term weather events affect the disposition of herbicide. And weather and climate can influence herbicide dynamics both during application and for months afterward.

During spray application, weather most directly influences droplet size or movement (weather is less relevant for pellet and granule applications because their size and weight infer a very low potential to move laterally in air during application (Birchfield 2003)). During application, either high or low wind speeds can expand the spatial distribution of drift and elevate water quality concerns, particularly if wind direction is from the application unit toward a water body. Winds directed away from water bodies are best, but often because herbicide treatment is on both sides of a stream, this condition is hard to implement.

Stable atmospheric conditions, often occurring during inversions "... are worse case conditions for pesticide drift" (Rashin and Graber 1993) because little vertical air mixing occurs and drift can transport long distance (USDC NOAA 2002b). Moderately low wind speeds may be optimum in that they increase spray drop impact efficiency relative to low winds, thereby reducing droplets available for deposition onto water bodies (Payne et al. 1989, cited in Rashin and Graber 1993).

Relative humidity and air temperature during spray application influence droplet evaporation rate, when water is used as the herbicide carrier. Evaporation rate is inversely related to humidity; drier air allows more evaporation, and consequently smaller droplets and more drift. Similarly, higher air temperature correlates directly with evaporation rate; the higher the temperature the greater the evaporation rate (Rashin and Graber 1993, USDC NOAA 2002b).

Rainfall timing and amount critically drive herbicide movement in runoff, particularly when the first runoff-producing rains occur soon after application and entrain herbicide into runoff before decomposition progresses sufficiently to lower herbicide levels (NCASI 2000, Chapel et al. 2001, USDC NOAA 2001). Besides moving herbicide in runoff, the rain can hasten leaching of herbicides, especially with leachable herbicides applied to highly permeable soil low in organic matter (Alabama Cooperative Extension 1999, Mahler et al. 2002); spikes of herbicide concentration in surface water are commonly associated with post-application rain events and have occurred at low levels for years after application in some locations (USDA Forest Service 2001, 2003b). Leaching is also correlated with rainfall amount; areas with high rates of rainfall may have large amounts of water percolated through the soil, especially if there is no runoff (Mahler et al. 2002).

Groundwater

Although many detections of herbicide in surface water are due to inadvertent herbicide deposition on surface water through drift at the time of application, and runoff associated with rainfall events after application, movement through groundwater is a pathway of

entry of herbicide to surface waters. And herbicide contamination of groundwater itself can be a concern.

Groundwater sources of surface water contamination are generally minimal for many herbicides because decomposition of herbicide by microbial action and other processes is quicker than the time taken for herbicide-laden water to move through groundwater to surface waters. Travel time to groundwater decreases as the depth to groundwater decreases, and generally the depth to groundwater is least in spring and greatest in late summer. If spring rains come shortly after herbicide application and the water table is close to the surface, a greater potential for groundwater contamination exists. (Mahler et al. 2002)

In areas where groundwater is close to the soil surface, contamination from herbicides is a greater threat. The shallower the depth to groundwater, the less soil there will be to act as a filter and the less chance for degradation or adsorption of herbicides. In humid regions, groundwater may be only a few feet below the surface of the soil. If rainfall is high and soils are permeable, water carrying dissolved herbicides may take only a few days to percolate downward to groundwater. In arid regions, groundwater may lie several hundred feet below the soil surface, and leaching of herbicides to groundwater may be a much slower process (Alabama Cooperative Extension 1999).

Geologic Conditions

Herbicides are more likely to leach in locations where geologic strata between the soil and groundwater are highly permeable. Gravel deposits, and other highly permeable materials, allow water and dissolved herbicides to percolate downward to groundwater. Clay layers are much less permeable and thus inhibit the movement of water (Alabama Cooperative Extension 1999).

Proximity of drainage ditches and other water bodies increases the likelihood for herbicide entrained by rainfall runoff to enter surface water. Drainage wells, abandoned wells, and sinkholes pose similar hazards for groundwater contamination (Alabama Cooperative Extension 1999).

Topography

Topography, including the size, shape, aspect, slope steepness, and slope length of landforms, affects the general drainage characteristics of a landscape and can impact both surface runoff losses of herbicides and sub-surface pathways. Even slightly soluble herbicides and those strongly adsorbed to soil particles can be carried downslope in stormwater, with steeper slopes elevating this hazard (Durkin 2003). Flat landscapes, areas with closed drainage systems where water drains toward the center of a basin, and especially sinkhole areas, are more susceptible to groundwater contamination (Alabama Cooperative Extension 1999).

When drainage density is high, it can be difficult to determine if small channels have live water (Rashin and Graber 1993). This difficulty increases the likelihood of inadvertent

direct spray onto live water. Scale becomes important if drainages are closer together than can be readily compensated for by accurate displacement of spray swathes.

On steep terrain, the preferred method of flightpaths parallel to the stream may be impossible because of aircraft safety consideration, although parallel swaths are probably the most effective method of buffering. Steeper sites also generally require higher flying, which spreads drift (University of Arizona 1983, cited in Rashin and Graber 1993). Theoretically, herbicide BMPs should be more effective on flat terrain where aircraft can fly closer to the ground (Rashin and Graber 1993).

Herbicide Behavior in Water Bodies

Once a herbicide enters surface water, its disposition depends on a variety of factors, including it's chemical properties in water (e.g., persistence and solubility) and properties of the hydrologic regime of the water body (travel time, depth, solids concentration, and processes that degrade the herbicide) (Rashin and Graber 1993, Chapel et al. 2001).

The mixing zone size needed to reduce or dilute downstream herbicide levels below any threshold effect concentration is a critical parameter. Mixing zone size can vary greatly and can depend upon the volume of herbicide input (e.g., spill or drift), the volume of the water body (e.g., 1 cfs vs. 30 cfs), the entry point (e.g., gravel bar inundation or drift deposition), and turbulence, which is generally greater for small but steep headwater streams. Hydrologically complex waterways with meanders, pools, riffles, and eddies that accelerate mixing and dilution are more likely to disperse contaminants than simplified waterways with consistent channel velocities that allow contaminants to maintain a more consolidated profile (Lee 1995, Heard et al. 2001, cited in USDC NOAA 2003e). Mixing distances are shorter in smaller streams and mixing is slower when the discharge point is near the streambank (Heard et al. 2001, cited in USDC NOAA 2003e).

The relatively limited information available for herbicides used in forestry suggests that downstream concentrations vary greatly for a given herbicide. Examples collated by Rice (2003) for picloram include:

- Evans and Duseja (1973)
  - Runoff samples from drainage ditch with no base flow.
  - 1.56" rainstorm in first week after spraying.
  - After 12 weeks all concentrations were ≤ 0.001 ppm and within 1 year picloram was not detectable.

Site	Rate (lb/ac)	Acres sprayed	Percent of watershed	Concentration of picloram (ppm) Distance from treated area (m)			
				5	10	100	1000
I	1	1.1	54	1.082	0.771	0.058	0.017
	2	1.2	83	2.716	1.851	0.051	ND
II	1	1.6	84	0.561	0.486	0.029	ND
	2	2.1	85	0.512	0.312	0.078	ND

ND = non-detectable

- Mayeux and others (1984)
    - Direct injection to stream of 1.2 gal T22K (2.8 lbs or 1,270 grams potassium salt).

Meters From Injection Point	Maximum Stream- flow (cfs)	Maximum Picloram Concentration (ppm)	Percent Of Total Injection
90	183	13.720	72.9
1,170	413	0.470	16.1
5,400	1,871	0.005	0.13

- Johnsen and Warskow (1980)
    - Direct injection of 1.5 lbs of picloram to produce 6.258 ppm picloram in mixing flume.
    - Streamflow was approximately 1.3 cubic feet/second over the 4 mile positive sample length of stream.
    - Two days after the injection concentrations were at or near the detection limit of 0.001 to 0.004 ppm at the 0.4 to 1.6 km sample points.

Distance (m)	Average concentration (ppm)
At Mixing Flume	6.258
400	1.630
800	0.497
1,600	0.282
3,200	0.010
6,400	0.001
9,700	ND

One ramification of downstream dilution and decreases in herbicide concentration is the need in monitoring projects to sample surface water immediately downstream of treatment units before confounding effects like dilution ameliorate concentration levels.

Detectability of Herbicides in Surface Waters

Ecosystem effects of herbicides are most basically identified by changes to biota or detection of the chemicals in the water. Detectability is partially a function of technology; as technology improves lower and lower chemical concentrations become detectable. Most forestry herbicides would often be undetectable in surface waters under operational (1 ppb) detection limits after the first post-application storms (Bush 2003). This does not mean that with research grade equipment detections would not be made. Rather "operational" detectability presumes use of equipment and technologies that are at least marginally within the range of resources available to land management agencies. Operational detectability also implies reproducibility of results. Currently detection at one ppb can be independently reproduced for many herbicides and is economically viable for some agencies. Detectability at lower concentrations is problematic in that detections in the part per trillion or part per quadrillion range are seldom reproducible by independent means (e.g., a second type of analysis). US EPA asks for a second method of analysis to confirm positive detections (Bush 2003).

Equipment is now available, albeit at high cost, to detect extremely low herbicide concentrations (e.g., part per trillion range). At these low concentrations chemicals with

herbicide-like properties are detected naturally in plants, presumably to serve some sort of protective purpose. At these low levels the source of the herbicide cannot be readily determined. Rainwater transported by atmospheric processes could be a source, as could plants. At such low levels linking detections to herbicide application is very problematic (Neary 2003).

Because of their high water solubilities, herbicides commonly used in forestry will quite likely actually exist in surface waters, even if they can't currently be detected (J. Michael, FS Research). Conditions minimizing herbicide detectability include:

- Acidic soil—which hastens herbicide degradation
- Fast-degrading herbicides
- Dry weather within the first month after application—to lower chances of runoff or water reaching channels before the herbicide degrades into non-toxic compounds
- Un-violated buffer
- Sloppy sampling protocols (e.g., sampling at wrong time)

Summary of Factors Influencing the Potential for Detection in Surface Waters, Relative Leachability and Runoff Potential for Selected Herbicides

Table 1 summarizes the risk of herbicide detection in surface water by major herbicide, soil, site condition factors, and by management practices.

A multitude of herbicide fate and transport research studies have been conducted. Herbicide detections documented in some of these investigations are listed in Appendix D, and addressed in narrative form in Appendix E, fate and transport summaries for several herbicides widely used by federal land management agencies. Table 2 lists characteristics of selected herbicides. In Table 2 low half-live values imply short herbicide persistence and low soil sorption values imply low binding to soil.

Table 1. Summary of Surface Water Detection of Herbicide by Major Parameters (after Alabama Cooperative Extension 1999).

	Low Risk	High Risk
Herbicide Properties:		
Water Solubility	Low	High
Soil Adsorption	High	Poor
Volatility	High	Low
Persistence in soil	Short half-life (a few weeks)	Long half-life (several months or more)
Soil Properties:		
Permeability	Fine clay	Coarse sand
Organic Matter	High	Low
Macropores	Few, small	Many, large
Site Conditions:		
Depth To Groundwater	Deep (20 feet or more)	Shallow (10 feet or less)
Rainfall	Small volumes &/or not concurrent with application	Large volumes &/or concurrent with application
Topography	Distant from water body	Proximate to water body
	Moderate-low drainage density	High drainage density
	Flat to slightly slope treatment unit	Steeply sloping treatment unit
Wind direction	Away from water body	Toward water body
Wind speed	Low but not completely calm	High or calm
Relative humidity	Moderate to high	Low
Geologic conditions	Low permeability strata	High permeability strata
Management Practices:		
Application Methods	Ground granules, pellets, or application to individual plants	Aerial spray, fine spray
Application frequency	Infrequent	Frequent
Application timing	Dry season	Concurrent with rainfall
Rates	Low volume used	High volume used

Table 2. Selected Properties of Several Herbicides (after Seelig 1994).

Herbicide[1]	Field half life in soil (days)	Soil sorption (ml/g)	Water solubility	Relative leachability	Relative runoff potential
2,4-D	10	20	High	Small	Medium
Clopyralid (Lontrel, Reclaim)	40	6	High	Large	Small
Dicamba (Banvel)	14	2	High	Large	Medium
Glyphosate (Roundup)	47	24,000	High	Small	Large
Hexazinone (Velpar)	90	54	Moderate	Large	Small
Imazapyr (Arsenal, Chopper)	90	100	Moderate	Large	Small
Metsulfuron-methyl (Ally)	30	35 (pH 7)	Moderate	Large	Medium
Picloram (Tordon)	90	16	High	Large	Small
Sulfometuron-methyl (Oust)	20	78 (pH 7)	Low	Large	Medium
Triclopyr (Crossbow, Access, Garlon, Grazon)	46	780	Low	Medium	Large

[1] Field half-life, soil sorption, and leaching potential are taken primarily from Wauchope et al. (1992, cited in Seelig 1994). Half life and sorption values are variably quantified in the literature, and the values cited here are central tendencies for these parameters.

HERBICIDE BEST MANAGEMENT PRACTICES

A variety of BMPs are used to help ensure that water quality and stream habitat are put at reduced risk from herbicide application. The primary focus of these practices is providing controls on sources of herbicides to reduce their contact with water bodies. Relatively few herbicide BMPs are designed to decrease the amount of soil lost to surface waters or to reduce water runoff. Appendix F groups herbicide BMPs for selected states, and some Forest Service regions, into those dealing with—

- Pesticide use planning.
- Label directions and legal requirements.
- Monitoring and evaluation.
- Cleaning and disposal of pesticide containers and equipment.
- Streamside and wet area protection during spraying.
- Controlling pesticide drift during aerial spraying.
- Pesticide spill prevention and contingency planning.
- Material safety data sheets.
- Community notification.

The streamside/wet area protection and drift control practices, along with the label/legal directives most directly affect on-the-ground operations. These BMPs each incorporate many separate, but related practices that could also be segregated with respect to either primary application method--aerial vs. ground. For instance, orienting aircraft flightpaths parallel to buffer borders relates solely to aerial application. Similarly, spray nozzle size and orientation relate primarily to aerial application whereas wind speed criteria can relate to both ground and aerial application modes. The Herbicide Dynamics section addresses some of the ramifications of these distinctions.

The effectiveness, and to some extent the specific implementation of, herbicide BMPs are site and herbicide-specific. Soil depth, texture and structure, for instance, influence infiltration rate which influences herbicide retention time in a buffer and the consequent rate of chemical degradation. Slope of the treatment unit partially controls the rate of potential runoff entering streamside buffers and the rate of subsurface herbicide movement. Herbicide-specific fate and transport properties similarly can influence how BMPs are specified. For instance, glyphosate adsorbs strongly to many soils (SERA 1996), with only a slight tendency to leach in soil (Schuette 1998). Buffers for glyphosate, especially if ground-applied, have been narrower than for some other herbicides, like hexazinone, that are relatively persistent in soil (Extoxnet 1996) and have a high probability of moving to groundwater (US EPA 1994).

Questionnaire Responses

Most of the BMPs listed in Appendix F are used by the respondents, with over three-quarters using buffers or other streamside protection measures. Weather criteria, label directives, storage/spill/transportation safeguards, drift controls and cleaning/disposal measures are also used, in order by declining frequency.

Over one-half of the respondents use label directives, state regulations, and organizational directives to identify necessary BMPs. Almost one-third use planning documents for this purpose.

The respondents cite a variety of reasons for determining if buffers are needed; no one or even several reasons is more commonly cited than others. Proximity to sensitive resources and stream type are cited as reasons by 25% of the respondents; weather, geomorphology, regulatory influence, potential to affect beneficial uses, prior monitoring, forest practice regulations, risk assessments, label requirements, literature review and organizational directives are each cited in equal proportion.

Wind speed limitations and prohibition of spraying if precipitation is imminent are the two primary weather criteria cited by the respondents.

A variety of drift criteria are cited, with almost equal frequency, by the respondents. The criteria include droplet size, distance from nozzle to vegetation, directional spraying, monitoring with colorant, and still wind/no rainfall among others. One-half of the respondents spray herbicide with large droplets under low pressure.

BUFFERS

Buffers or filter strips are a commonly-applied BMP. "Buffer" is used here to mean a strip of land between a water body and the adjacent terrestrial upland forest or rangeland managed to (1) prevent direct deposition onto surface water as drift or inadvertent direct spray, and (2) attenuate herbicide in runoff and sub-surface flow before it reaches the surface water.

In a summary of riparian area functions, the National Resources Conservation Service (cited in National Research Council 2002) stated that as much as 50% of pesticides in surface water runoff and 75% of the sediment load can be removed by buffers. And Heady and Child (1994 cited in USDC NOAA 2003a) stated "... risks of contamination [to aquatic biota from herbicides applied directly to stream channels] can be reduced if adequate no-spray buffers are maintained." Unfortunately, these, and similar statements, refer largely to the agricultural environment; systematic research directed specifically at buffer effectiveness in forest and rangeland conditions is not extensive.

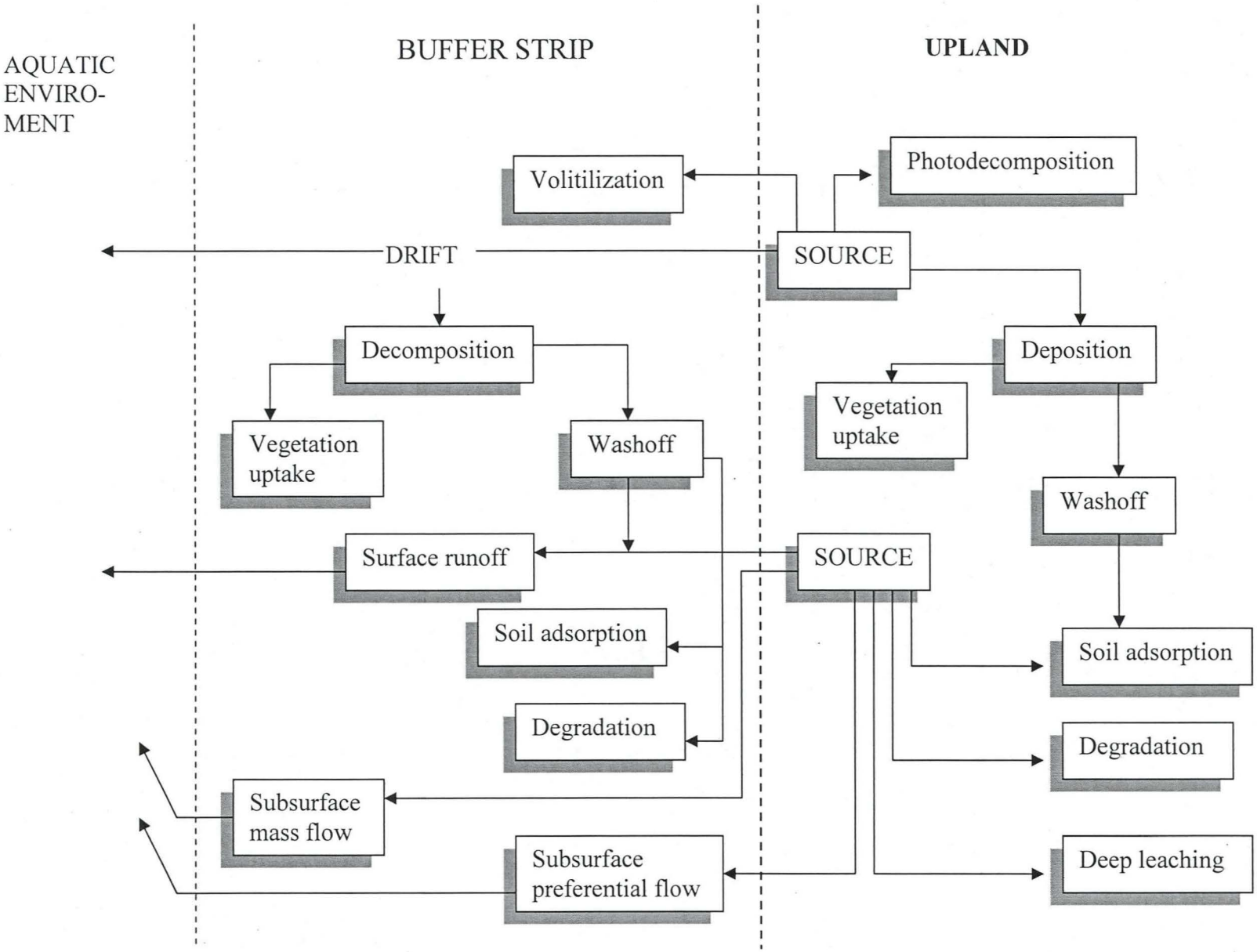
Streamside forestry buffers can be controversial in that "wide" buffers can ostensibly eat into the land base for timber harvesting or other management objectives. Also, to optimize reforestation (at least on some national forests in California) vegetation within buffers that hasn't been affected by herbicide may need to be manually removed. Manual removal is costly and time intensive and the incentive is to narrow the buffer while still meeting water quality objectives (Frazier 2003). Inadequate understanding of the relationship between buffer width and water quality effectiveness also adds uncertainty to buffer design and use.

Buffer Functions

Prevention of direct deposition occurs with the buffer acting as a safety zone providing space for unanticipated herbicide spray, or less likely, off-target herbicide pellet dispersion. For spray drift, Giles (2003:6) described buffers as providing "...a displacement between the application site and the sensitive area. Within this displacement, the fallout portion of the spray drift steadily decreases. With a sufficiently wide buffer, the spray fallout can decrease to a level below that of a biologically significant level for the ecosystem and the organism of interest."

On-the-ground attenuation is primarily by deposition, infiltration, adsorption, uptake, decay and filtering of herbicide-laden sediment and dissolved herbicide in overland and sub-surface flow (Figure 3) (Phillips 1989 cited in Comerford et al. 1992). Streamside buffers can slow the movement of herbicide-laden runoff and allow suspended particles to settle out before reaching surface waters. Vegetated buffers are substrates for microbial decomposition of chemicals; they can change dissolved oxygen content of the soil to further degrade herbicides (Zaber 2003).

Figure 3. Herbicide Movement Through a Buffer Strip (after Commerford et al. 1992).



Although buffers are well-accepted tools for reducing pollutant entry into water bodies, the efficacy of forest and rangeland riparian buffers in trapping herbicide before the chemical enters water bodies wasn't well understood in 1992 (Comerford et al. 1992) and still isn't quantitatively predictable (Klapproth and Johnson 2000, Dosskey et al. 2001).

Buffers affect herbicides by influencing the rate of herbicide degradation and movement through the pathways identified in the Herbicide Dynamics and Water Quality section. Herbicide in water-born sediment entering a buffer is physical filtered, thereby immobilizing some herbicide in the sediments. Vegetation plays a key role in the filtering process by slowing surface water velocity and increasing the residence time of the herbicide, thereby allowing more time for infiltration, soil adsorption, vegetation uptake and degradation to occur.

Predicting the effectiveness of buffers, and relating buffer width to effectiveness of attenuating herbicide entry into water bodies, is site specific. A myriad of plant, animal, soil, climate and microbiological factors influence the attenuation rates. Rates are also herbicide-specific due to the range of herbicide fate and transport characteristics, which in turn are partly contingent upon application mode and chemical formulation.

Modeling

Improvements in the simulation of processes associated with drift are on-going, and progress has been made in modeling drift in relation to buffers at least partly because drift isn't herbicide-specific per se. Aerial spray application of herbicide produces liquid droplets that do not vary by herbicide, and although a variety of factors influence drift (e.g., droplet size spectrum) these factors do not vary by herbicide. Dissolved or sediment-bound herbicide does move in a herbicide-specific manner and modeling of herbicide moving with sediment or in water across a buffer is less advanced (Durkin 2003, H. Thistle, personal communication, cited in USDC NOAA 2003b). Herbicide fate and transport models (e.g., GLEAMS) don't model buffers or in-stream dilution between a point of herbicide entry into a water body and potentially sensitive locations downstream (USDI NOAA 2001).

Spray drift and buffer modeling nevertheless needs improvement. USDC NOAA (2003b) states that available models do not consider forest canopy cover, droplet runoff from different foliar types and forest topography. And correlations between the percent of spray hitting the target haven't been made with water quality information to determine if the model predictions can function as a surrogate for water quality controls.

As a summary statement on the status of knowledge of buffer dynamics, Dosskey (2002) stated:

> A great deal of professional judgment is still required to extrapolate current knowledge of buffer functions into broadly accurate estimates of water pollution abatement in response to buffer installation on crop land.

This statement refers to sediment and nutrient relationships primarily. Because less is known about herbicide-buffer relationships, and because less is known about buffer dynamics in forest and rangeland, Dosskey's comment probably understates the status of ignorance of herbicide-buffer dynamics in forestlands.

Buffer Effectiveness

Buffer effectiveness, in terms of either reducing the percentage of herbicide reaching water bodies, or measured by peak concentrations of herbicides that have passed through buffers, varies widely. This is probably due to a variety of reasons, with a major factor being the potential sensitivity of effectiveness to small changes in buffer width, at least for aerial spraying because attenuation of herbicide sprayed at or near the edge of a buffer is non-linear across the buffer; the greatest decrease in drift is nearest the edge by the application. A ramification of this phenomena is that small increases in buffer width near the treatment boundary can provide "... much more relative benefit than even large increases in already wide buffer zones" (Giles 2003:6).

The preponderance of research on buffers is from agricultural studies. As of 1992, Comerford et al. (1992) stated "There has been no single, major watershed study on the effects of buffer strips on forestry pesticide offsite movement." No publications are known since 1992 that systematically relate buffer width or other properties directly to water quality. And USDC NOAA (2003b) recently reiterated this point in stating that although buffers proposed in a noxious weed project "... should maximize infiltration rates and minimize over-ground flow, ... it is unknown how effective they will be in prevent chemical from entering stream channels. Research has not yet been done on effectiveness of application buffers in steep bunchgrass communities ... ."

Many pesticide "fate and transport" studies include buffers, as do monitoring reports. Results of several fate and transport studies are tabulated below for forestry applications of selected herbicides (Comerford et al. 1992) through the late 1980s, and from more recent operational USDA Forest Service monitoring in California (Appendix D). Comerford et al. (1992:27) described the fate and transport studies as not attempting to assess the effects and functions of differing buffer strip sizes; "[W]here strips were used, other criteria determined the strip size."

The Comerford et al. (1992) summary does not clearly relate buffer effectiveness to any single causative factor (like buffer width) because buffer efficacy varies due to the many factors affecting pesticide transport; "[P]esticide chemistry, application rate, distribution method, buffer size, and weather conditions were very important inn determining how well buffer strips worked" (Comerford et al. 1992:27). Undocumented occurrences, like herbicide spills, can also cause elevated peak concentrations.

Pesticide	Application		Landscape[1]		Buffer (m)	Peak concen-tration (mg/m^3)	Ref.[2]
	Rate (kg/ha)[3]	System	Type	Stream			
Dicamba	1.1	Air spray	CAS	PS	0	37	A
Hexazinone	2.0	Ground spotgun		PS	1	9	B
Hexazinone	1.4	Ground spotgun	AM	PS	15	16	C
Hexazinone	1.7	Air pellet	TLP	PS	20	0	D
Hexazinone	1.7	Air pellet	P	EC	0	442	E
Hexazinone	1.8	Air pellet	P	PS	0	2400	F
Imazapyr	2.2	Air spray	UCP	PS	0	680	G
Imazapyr	2.2	Air spray	UCP	PS	15	0	G
Picloram	5.0	Ground spray	AM	PS	140	10	H
Picloram	5.6	Air pellet	UCP	EC	0	442	I
Picloram	10.4	Ground pellet	AZM	EC	0	370	J
Picloram	2.3	Air spray	OCR	EC	0	64	K
Picloram	2.2	Ground pellet	TP	EC	0	2826	L
Sulfometuron methyl	0.4	Ground spray	LCP	EC	5	7	M
Sulfometuron methyl	0.4	Aerial spray	UCP	PS	15	44	N
Triclopyr	11.2	Air spray	AM	PS	0	80	O
Triclopyr	2.0	Ground spray	LCP	EC	5	2	P
2,4-D	2.2	Air spray	WHP	PS	30	2	Q
2,4-D	4.6	Air spray	OCR	EC	0	22	K

[1] Landscape type: LCP=Lower Coastal Plain, UCP=Upper Coastal Plain, CAS=Cascade Mountains, AM=Appalachian Mountains, P=Piedmont, TLP=Tennessee Low Plateaus, AZM=Arizona Mountains, OCR=Oregon Coast Range, TP=Texas Prairies, WHP=Wyoming High Plains
Stream: PS=perennial stream, EC=ephemeral channel

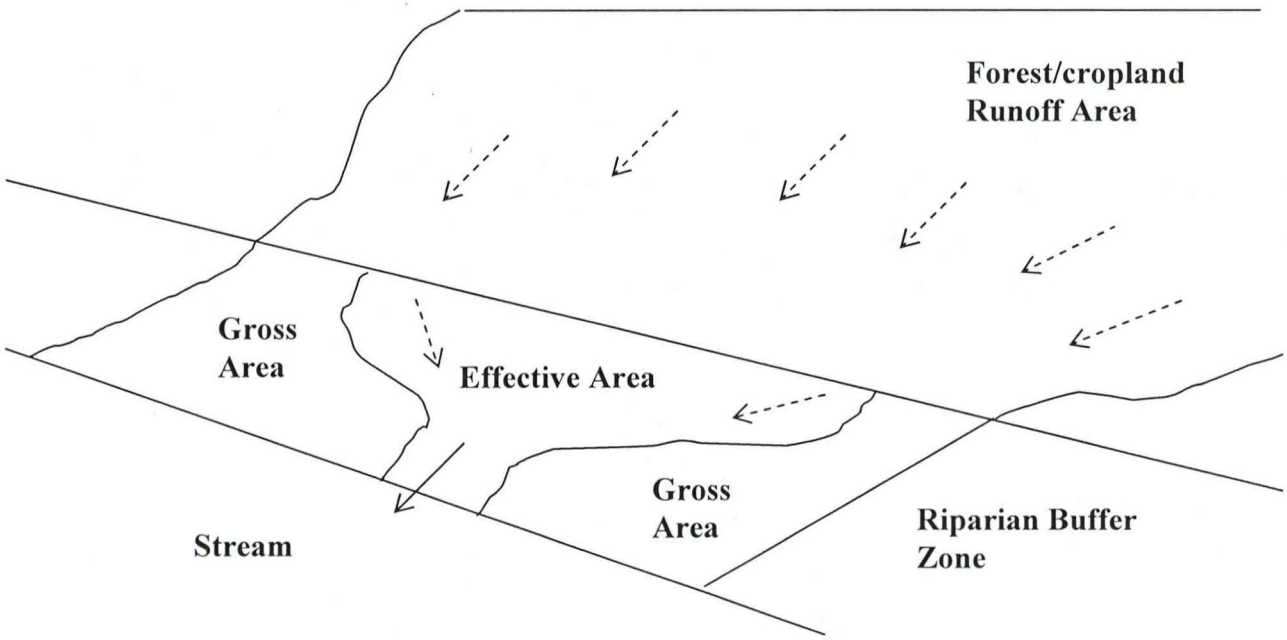
[2] References: A= Norris and Montgomery 1975, B=Bouchard et al. 1985, C=Lavy et al. 1989, D=Neary 1983, E=Neary et al. 1983, F=Miller and Bace 1980, G=Michael 1986, H=Neary et al. 1985, I=Michael et al. 1989, J=Davis and Ingebo 1973, K=Norris et al. 1982, L=Bovey et al. 1978, M=Neary and Michael 1989, N=Michael and Neary 1987, O=McKellar et al. 1982, P=Bush et al. 1988, Q=Schroeder and Sturges 1980

[3] Active ingredient

The real-world effectiveness of buffers for reducing runoff-caused water quality effects is less than theoretically possible because flow is typically concentrated through only parts of the buffer; flow is not spatially uniform and channeling caused by microrelief reduces the surface area of the buffer that comes into contact with flow (Figure 4) (Dosskey et al. 2002). This reduces the effectiveness of the volatilization, washoff, soil adsorption, degradation and vegetation uptake processes and also reduces sediment capturing effectiveness. Sub-surface flow may similarly be spatially heterogeneous; soil

macropores can quickly move pesticides through the subsurface, thereby countering beneficial effects of buffers. For instance, Dosskey et al. (2002) modeled theoretical efficiencies of sediment removal at four Nebraska farms at 99, 67, 59 and 41%. Calculated non-uniform flow lowered the estimated efficiencies to 43, 15, 23 and 34% respectively. In this study the actual buffer area that contacted runoff water (the effective buffer area) ranged from 0.6 to 81% of the gross buffer area.

Figure 4. Schematic depiction of effects of microrelief reducing gross area of buffer to effective area. Gross area is the area that runoff would contact if flow were dispersed across the entire buffer area to the stream. Effective area is the actual area of runoff travel to the stream. (after Dosskey et al. 2002)



The National Research Council (2002) further pointed out that high effectiveness of buffers may be over-rated:

> In reality, most buffers and riparian areas achieve only a fraction of their reported pollutant trapping potential. Most of the trapping studies reported by researchers have been short term in nature and were conducted under very controlled conditions that minimized the influence of factors—such as concentrated flow & long-term accumulation of pollutants – that influence riparian zone performance in nature. … In addition, most of these studies report on riparian zone effectiveness for water quality protection only in the first few years after establishment [implying that long-term effectiveness of un-maintained buffers is unknown].

Buffer Widths

Suggested buffer widths for protection of aquatic resources from herbicides vary widely, as suggested above, because of the multitude of factors influencing herbicide movement in the air, on the ground or through subsurface processes, as well as chemical-specific properties of the herbicides, and the sensitivity of aquatic resources. Widths from a few meters to over several hundred m have been used, and cited as effective (Zaber 2003, NRC 2002, Giles 2003).

Table 3 exemplifies buffer widths based on stream type and used currently at a national forest in California. These widths benefit from feedback from years of water quality monitoring (Eldorado National Forest 1995, 2000, 2002; Bakke 2001). Buffers on this Forest are not aimed at zero detection in surface waters, but rather at the biological standard established by the local regulatory agency. Buffer widths proposed by USDI BLM for noxious weed control in Idaho are based in maximum wind speed, herbicide application method, and toxicity to local aquatic species (Table 4) (given natural variability in wind speed on the scale of minutes, it's unclear how the wind speed variable is effectively incorporated into width determinations) . The state of Oregon similarly segregates buffer widths by stream type but also by herbicide application method (generally 60' for aerial and 10' for ground) (Oregon Forest Resources Institute 2002). For an insecticide project in Oregon, BLM proposed sizing buffers "... by the flight direction of the aircraft, the height of the trees being treated, weather conditions (primarily wind direction and speed) and the pilot's ability to regulate the dispersal of the spray" (USDC NOAA 2001). NCASI (2000) compared widths needed to achieve 90% effectiveness ("measured as LC10 or as <0.1% of application rate") between aerial and ground application techniques and noted that "Ground applications require considerably smaller buffer widths to achieve 90% effectiveness." Widths are cited as ranging from 5 to 131 m to achieve 90% effectiveness for aerial treatments and 20 to 50 m for ground treatments (NCASI 2000) (it's not clear why the ground treatment widths appear larger--5 vs. 20 m.) As a final example, the state of Washington has an ornate scheme for buffer width determination based on application method, stream type, spray nozzle type, wind factor and application height (Washington Dept. Natural Resources undated). NCASI (2000) also noted that buffer widths are often the most argued item in debates about appropriate spray control projects.

Comerford et al. (1992) concluded that for forestry applications, "... strips of 15 m or larger were effective in minimizing pesticide residue contamination of streamflow". These authors added that conditions, such as prevalence of subsurface, macropore flow, can cause much wider buffers to be ineffective in completely keeping residues out of surface water. One relatively solid conclusion also is that increasing buffer width for drift control will have diminishing returns.

Table 3. Buffer widths (feet) currently used on the Eldorado National Forest, in California's central Sierra Nevada (see also questionnaire response from the Forest, Appendix B).

Herbicide	Highly significant perennial/ intermittent streams[1]	Significant, perennial/ intermittent streams[1]	Moderately significant, perennial/ intermittent streams	Intermittent or ephemeral streams of minor significance	Wet area, springs, meadows
Glyphosate (Accord)	50	25-50	25	0-10[2]	25
Glyphosate (Rodeo)	0	0	0	0	0
Clopyralid	75	50	25	0	50
Triclopyr	100	50-100	50	25	
Hexazinone	200	100-200	100	50	

[1] On large class 1 and 2 streams where a flood plain exists, increase buffers to stay out of the flood plain.
[2] 25 feet where riparian vegetation or running water is present.

Table 4. Buffer widths proposed by BLM for a noxious weed control project in Idaho (USDC NOAA 2002).

Buffer	Max. wind speed (mph)	Herbicide application method	Aquatic level of concern
>300' from outer edge or riparian area for fish bearing waters	5	Aerial	Low, moderate and high
>200' from outer edge or riparian areas for fish bearing waters	5	Aerial	Low and moderate
>150' from outer edge of riparian areas for non-fish bearing waters	5	Aerial	Low, moderate and high
0-100' from live waters or shallow water tables	N/a	No applications of picloram	N/a
>100' from outer edge of riparian areas for non-fish bearing waters	5	Aerial	Low and moderate
>100' and areas outside riparian areas	8	All ground/ broadcast spraying	Low, moderate and high
>50' and areas outside riparian areas	15	Wicking, dipping, painting and injecting	Low and moderate
15-100' from live water or shallow water tables; or within riparian areas	8	Ground/spot spray (no broadcast boom), wicking, wiping, dipping, painting, injecting Selective spraying of target species only	Low and moderate
<15' from live water or shallow water tables	5	Backpack or hand-pump sprayer, wicking, wiping, dipping, etc. Selective treatment of target species only	Aquatic approved herbicides only No surfactants authorized

Interviews and Questionnaire Responses

Given the wide variety of buffer widths used, and the uncertainty of buffer effectiveness in forest and rangelands, important questions associated with effectiveness of herbicide buffers for noxious weed control and reforestation are—

- How are buffer widths determined?
- How are widths determined to be effective?

A summary of comments from interviews and questionnaire results on buffer width determination and effectiveness follows (see also Appendices A, B and C):

USDI Fish and Wildlife Service

Buffer zones for aerial herbicide application by BLM for noxious weed control were adjusted on a site-specific basis in response to FWS concerns for specific active herbicide ingredients. The process for buffer width specification by action agencies isn't transparent; models (e.g., AgDrift) and risk analysis appear to be commonly-used tools. Extrapolation of the agriculturally-based models to forested conditions is not ideal. Current modeling approaches, with the addition of a safety factor, are probably the best we can do with currently-available models and scientific knowledge—but determination of the safety factor itself is problematic. Before devoting significant money and staff time attempting to determine buffer widths, we need a better understanding of what active ingredients are doing to fish, and what chemical data (e.g., water column sampling) means re biota before instituting detailed monitoring (T. Buerger, FWS).

For agricultural applications, FWS determined 300' buffers to be appropriate, although 500' is recommended for more toxic chemicals. The 300' width is based partially on US EPA spray drift studies, the general lack of data on combined aerial drift and surface runoff through buffers, and NRCS runoff studies (E. Snyder-Conn, FWS Refuges).

USDC NOAA

Scientific uncertainty about buffer effectiveness, in combination with the complexity of variables relevant to buffers, complicates buffer width determination and opts for conservatism in width designations. Width information on product labels can be suspect because typically US EPA isn't consulted re the label information, and alternative methods for width determination may give widths that differ from label directives. Surfactants and other adjuvants typically aren't clearly incorporated into width directives on product labels. Potential, but largely unknown, sub-lethal effects on aquatic biota are another impetus for conservative width determinations (R. Anderson, NOAA).

Monitoring is critical in determining the efficacy of BMPs; without monitoring we don't know if buffers of differing widths are effective under varying conditions (R. Anderson, NOAA).

USDI BLM

On the Cottonwood District in Idaho, buffer width determination is by informal risk assessment using the GLEAMS fate/transport model, combined with knowledge of the toxicity of the proposed herbicide(s) to the target species (C. Johnson, BLM).

Widths are determined partially by the presence of sensitive areas, mainly streams (with distinctions between intermittent and perennial streams, and mainstem streams) or sensitive (e.g., known T&E) plant populations. Buffers are expanded beyond what is required on the herbicide label and standard BLM protocols. This is precautionary and not based upon any "science" per se. At the local scale they can't be tested to detect movement of herbicides through the soil or in water as that is prohibitively expensive and time consuming (L. Danly, BLM).

USDA Forest Service

Eldorado National Forest (California)—Buffer widths determinations are based on a combination of factors including the chemical properties and the labeled use of the herbicides being used, beneficial use of the water feature, and results from previous water monitoring. Buffer widths have been based on stream class (I, II, III, IV), stream type (perennial, seasonal, ephemeral), proximity to water feature (spring, reservoir, lake), and the beneficial water use of that specific feature or stream reach (domestic, municipal water, aquatic frog habitat, trout fisheries, etc.) (Eldorado National Forest).

The actual width decision is made by the deciding official, and remains in place for the duration of a project unless circumstances change. An example of a changed circumstance that occurred on the Eldorado National Forest was the 1996-97 storm events and resultant landslide activity in the South Fork American River canyon and Cleveland Fire area. Any proposed projects, including herbicide application, that could affect land stability were reviewed by the forest geologist and a hydrology review was also conducted to identify new hydrologic features, changes in channel morphology, and to assess the adequacy of the buffers used. Geologic and hydrologic reviews of herbicide treatments in the Cleveland Fire area were recommended on an annual basis and any units proposed for herbicide treatment that lie adjacent to or contain active landslide features were assessed in the field (Eldorado National Forest).

Results from water monitoring from previous years' herbicide application programs determine whether the buffers have protected water quality. If there is no detection then the buffers are assumed adequate although dilution effect of some larger streams may also be a factor. Any detections within the expected (predicted) rates may also indicate that these measures were also effective (Eldorado National Forest).

Kootenai National Forest (Montana)—Width determination is not well founded in science; it's hard to come up with a scientifically-based rationale for specific widths. The "one size fits all" approach is a problem. Often width decisions are based on a worse case scenario that may not be relevant to forestry applications (e.g., irrigation water protection, not forestry). Application rate and areal extent are not considered (e.g.,

widths are the same for a few acres of noxious weeds with low application rate as for agricultural field application) (E. Monnig, FS).

Nez Perce National Forest (Idaho)—The process for width determination is hard to generalize and depends upon a variety of factors including the environmental fate of the herbicide, it's toxicity properties, and site-specific soil textures. The Nez Perce National Forest gives the contractor guidelines and defers to the contractor for specific width determination. This approach is also taken with internal FS herbicide applications. There is a minimum width for any application. Herbicide choice is somewhat dependent upon proximity to water bodies; the Forest uses one set of chemicals for an upwind site and another set for treatment units closer to water (L. Lake, FS).

Payette National Forest (Idaho)--Recent buffer widths have been determined by Forest staff in consultation with NOAA/FWS (Level 1 discussions). This interagency team used product label and US EPA information overlaid by a conservative approach to width determination. There is some arbitrariness in this process; e.g., a "one size fits all" approach with 100' buffers. However, on a site-specific basis some locations could potentially be protected by 10' buffers with other locations needing 300' buffers. Would prefer functional, customized approach rather than one size fits all (P. Grinde, FS).

Pacific Southwest (California) Regional Office—The need for, and width of buffers on any individual unit is based on the proximity to nearby water, topography, weather, and stream class. For aerial treatments, a minimum buffer width is specified in a Regional Reforestation Final EIS. Site-specific analysis usually involves AgDrift or AgDisp deposition modeling. For ground-based treatments, widths are based on past experience and monitoring results. Early projects had wide, conservative buffers. With experience in monitoring these initial wide buffers were reduced until detections were seen (D. Bakke, FS).

Stanislaus National Forest (California)--For aerial applications a written authority (probably an EIS) requires 100' minimum buffers. For ground applications, professional judgment, trial/error experience, and the results of early tests with backpack sprayers all feed into buffer width determinations. In reforestation projects, an objective is to keep buffers narrow (to reduce the need for manual removal of competing vegetation) while still meeting water quality objectives. Buffer effectiveness is determined from water column monitoring results. Those results suggest that except for accidents, buffers and other BMPs are effective in meeting state-determined water quality standards (J. Frazier, FS).

Florida

Initial widths were largely based on intuitive experience, then verified after buffers were in place for a while. Verification is by bio-assessment that shows no significant difference in macro-invertebrate characteristics pre- and post-treatment (J. Vowell, Florida Div. Forestry).

Maryland

Label restrictions determine some buffer widths; others are added as operational standards. On Chesapeake Forest, buffers are set in the management plan, which can be adjusted through the interdisciplinary team process, along with consideration of research and precision for application equipment/techniques (A. Strang).

Montana

Buffer widths are determined (for noxious weeds in crop situations), sometimes with models, by considering soil composition, slope, groundwater depth, herbicide, etc. Buffer effectiveness is monitored, typically on approximately 25 projects/yr, by looking for effects on non-target vegetation. No water column sampling is done, although some groundwater testing may occur. Good communication with grantees (herbicide applicators) and comprehensive review of project reports also gets at effectiveness (D. Burch).

South Carolina

The need for buffers is determined by the type of water body present. Perennial streams, ponds, and lakes require a 40' forested primary SMZ. If the slope is >5%, then a secondary zone is required. Additional SMZ width is also required if trout waters are present. Intermittent streams require a 40' primary zone with the root mat, forest floor, and understory vegetation intact, and a secondary zone determined by slope (D. Jones).

National Council of the Paper Industry for Air and Stream Improvement, Inc.

Forest practice regulations, label requirement, company directives, and in some cases, modeling are used to determine buffer widths (G. Ice).

Discussion and Interpretation

On a coarse level, forest and rangeland buffers do limit herbicide entry into adjacent surface waters. The preponderance of information obtained from questionnaire responses, interviews and the literature suggests, however, that the efficacy of forest and rangeland buffers for trapping herbicide before it enters water bodies isn't quantitatively predictable. Understanding is incomplete in terms of predicting the amount of entry and relating buffer width to entry amounts. This is largely due to the myriad of biogeoclimatic site-specific and herbicide-specific variables that drive the buffer-herbicide dynamic. This complexity is increased by the multiple options for herbicide application.

No effective, systematic and reproducible methods for width determination appear to be available. This failing opts for conservative decisions on buffer widths by regulatory agencies. Methods used for width determination include modeling and professional judgment incorporating a variety of factors including stream type, the presence of

sensitive resources, herbicide toxicity, and results of any available water quality monitoring.

Available models apply best to aerial spray applications, and although research is on-going, simulation of drift in forest environments with complex terrain and vegetation combinations is not operationally validated. Relevant factors like forest canopy cover and droplet runoff from different foliar types are either not modeled or not modeled well. Modeling of runoff and subsurface herbicide movement through buffers, and of the combined processes of drift, runoff and subsurface movement are even less advanced.

Many of the site- and herbicide-specific variables complicating modeling also cause high variability in buffer effectiveness. Water column monitoring is used as a feed-back mechanism to infer buffer width (in)adequacy. The prevailing opinion, to the extent there is one, is that if water chemistry monitoring does not identify water quality problems, the widths are effective. This presumes a simplistic cause-effect relationship between buffer width and water chemistry that may leave out other contributing factors. Furthermore, budgetary and other resource limitations currently preclude water column monitoring for some projects. Because monitoring is seen as the primary evidence for buffer efficacy, without monitoring uncertainty increases and there is an impetus to institute wider buffers. This conservatism is amplified by uncertainty about effects of herbicides to aquatic biota (e.g., sub-lethal effects).

Few studies documenting the long-term effectiveness of buffers exist, and consequently long-term buffer effectiveness is largely unknown. Nevertheless, on-going maintenance of buffers is probably needed to recoup the highest possible effectiveness. This is indirectly documented by the influence of microrelief in agricultural buffers that can drastically reduce buffer effectiveness.

HERBICICDE BMP IMPLEMENTATION

The literature and the Internet were searched for information on herbicide BMP implementation. Because of the impetus in the Clean Water Act to address nonpoint source pollution through BMPs, and because of the focus of the Act on states, most documentation is from state programs. Most monitoring of herbicide BMPs on forest and rangelands is reported in the broader context of timber harvesting and/or site preparation BMP monitoring; no stand-alone herbicide BMP implementation monitoring results were identified.

Kilgore et al. (2002) reported that 33 of the states have monitored BMP implementation at some time. After the literature review and interviews, no documentation for forest or rangeland herbicide BMP implementation monitoring by state governments was found for Idaho, California, Colorado, North Carolina, Kentucky, Louisiana and Maine. All 50 states were not included in the information search and it is possible that other examples of implementation monitoring at the state level exist.

Two reports were found on herbicide BMP implementation monitoring by federal land management agencies; these are summarized below, after the state summaries. Implementation is also indirectly assessed in effectiveness monitoring by federal agencies that implicitly addresses the implementation of mitigation practices. NOAA also notes that drift card and vegetation monitoring for buffer implementation with aerial herbicide application is mandated for current or recent BLM and FS projects in several western states (USDC NOAA 2002a,b, 2003b,c).

This section initially summarizes documentation from the literature search and then lists opinions on BMP implementation and implementation monitoring from the questionnaire responses and telephone interviews.

Arkansas Forestry Commission (undated)

Statewide implementation monitoring of forestry operations in Arkansas has been reported three times, for surveys in 1998, 1999 and 2000-2001. The 2000-2001 survey primarily followed protocols recommended by the BMP Monitoring Task Force of the Southern Group of State Foresters and adopted in June 2002 (Southern Group of State Foresters 2002). Monitoring sites were randomly selected, with the number of sites based on the objective of statistical accuracy to +/- 5%. Candidate sites must have been harvested 1-24 months prior to the survey. Unit sizes were constrained to between 5 and 200 acres. Sampling was not stratified by ownership.

The survey questioned landowners about their familiarity with BMPs, their use of professional assistance and a written harvest agreement, and whether BMP compliance was required in the timber sale agreement. Questions answered as "yes" or "no" formed the basis of the assessment.

Two questions dealt with herbicides—

1. Evidence of leaks, spills or misapplications?
2. Evidence of application to SMZ zones?

All 52 responses to question 1 were "yes"; 33 of 34 responses to question 2 were "yes". No recommendations specific to herbicide BMPs were given.

Florida Division of Forestry (2002)

Florida has monitored forestry activities biennially since 1981 for BMP compliance. Each survey assesses a random sample of forestry operations on both public and private lands for compliance with all applicable BMPs. Sites are included from all counties having any level of forestry activity. The target number of survey sites per county is proportional to timber removal in the county. Candidate sites must have experienced silviculture treatment within the past two years, with some activity occurring within 300' of a water body. A random component is included in the site selection process.

In the assessment process as much of the treated area as possible is observed. All assessments are based on physical on-site evidence with no assumptions made about future actions. Scoring is at three levels: individual practices (yes/no), categories of practices (% of all of all applicable BMPs) and (3) overall site compliance (% of all applicable BMPs). All instances of non-compliance are described.

Results for herbicide BMPs are tabulated below for 2001 (Florida Div. Forestry 2002), 1999 (Florida Div. Forestry 2000) and 1997 (Florida Div. Forestry 1998) as number (and parenthetically percentage) of practices in compliance:

Practice	1997	1999	2001
Special Management Zone			
Kept aerial/mist-blown pesticides out of Primary Zone	10/10 (100)	10/10 (100)	11/11 (100)
Kept aerial/mist-blown pesticides out of Secondary Zone	9/9 (100)	7/7 (100)	9/10 (90)
Operations Adjacent to Canals			
Applied pesticides according to label?	0/0 (n/a)	0/0 (n/a)	2/2 (100)
Site Preparation and Tree Planting Operations			
Kept aerial applications of herbicides out of SMZ	15/15 (100)	13/14 (93)	22/23 (96)
Pesticide Use BMPs			
Used properly labeled pesticides for target pests	15/15 (100)	18/18 (100)	23/23 (100)
Applied pesticides according to labels	15/15 (100)	16/16 (100)	23/23 (100)
Directed pesticide only onto targeted area	15/15 (100)	18/18 (100)	25/25 (100)
Removed pesticide containers from site	6/6 (100)	18/18 (100)	26/26 (100)
Located chemical transfer/loading areas outside of Primary Zone	15/15 (100)	15/15 (100)	18/18 (100)
Cleaned spray equipment outside of SMZ	8/8 (100)	11/11 (100)	16/16 (100)
Forestry Operations			
Kept non-wetland pesticides out of wetlands	8/8 (100)	9/9 (100)	17/17 (100)

Georgia Forest Commission (undated)

Georgia has conducted four statewide audit surveys, in 1991, 1992, 1998 and 2002. The 2002 survey is the first to evaluate BMPs that were revised early in 1999. The assessment protocol and scoring methodology for 2002 was consistent with the revised recommendations made by the BMP Monitoring Task Force of the Southern Group of State Foresters and adopted in June 2002 (Southern Group of State Foresters 2002). Sites were selected in a stratified random sample proportional to the amount of timber harvested in each county. Sites could be on public land, or industrial or non-industrial private forests. Candidate sites must have had forestry operations within the two years prior to the survey.

BMPs were evaluated as individual practices, category of practices, and overall site, based on yes/no assessments to a variety of implementation questions. BMP compliance was also assessed, as acres or miles of practices. "Implementation" addressed implementation of BMPs; "compliance" addressed impacts or impairments. The two herbicide-related questions in the 2002 survey were:

- "It appears that all State and Federal laws regarding the storage, transportation, handling, application and disposal of all chemicals and containers are followed?"
- "It appears that chemical drift into sensitive areas has been avoided?

Twenty-three sites, and 2600 acres, were assessed in the 2002 survey. The herbicide BMPs were implemented at 97.8%; compliance was 100%.

Montana Department of Natural Resources and Conservation (2002)

The Montana Department of Natural Resources and Conservation has conducted BMP compliance monitoring on a biennial schedule since 1990. The 2002 publication describes the most recently available assessment.

Forty sites were assessed for one herbicide-related BMP, "Know and comply with regulations governing the storage, handling, application (including licensing of applicators), and disposal of hazardous substances. Follow all label instructions." The 40 sites comprised lands administered by state and federal governments, and industrial and non-industrial private landowners.

Site selection was based on—

- Recency of timber harvest (within 3 years of the audit).
- A portion of the sale located within 200' of a stream.
- At least 5 acres harvested.
- Removal of at least 3,000 board feet (east-side units) or at least 5,000 board feet (west-side units).

A random component does not appear to be included in the site-selection process. Each site is visited by a seven-person audit team, composed of a fisheries biologist, a forester, a hydrologist, a representative of a conservation group, a road engineer, a soil scientist

and a shared position of logging professional or representative of non-industrial private forest landowners.

Implementation ratings were "4" ("operation meets requirements of BMP") for all 40 sites. BMP effectiveness was also evaluated at these sites. All 40 sites were rated as having "adequate protection of soil and water resources". No further definition or explanation of the meaning of the "meets requirements" or "adequate protection" phrasing is given.

Oregon Department of Forestry 2002 (Oregon DOF 2002)

Forty-three randomly selected sites were evaluated in 1999 and 2000 for the three Oregon Forest Practice Rules applicable to pesticide treatments. These Rules address protection of riparian zone vegetation and label directions, and incorporate numerous sub-topics. The Rules are considered by the state of Oregon to be equivalent to BMPs. A total of 129 applications were assessed by an experienced, retired, state forest protection forester using a categorical rating system. Practices were assessed as "Exceeds", "Meets", or "Noncompliant." Any noncompliant situations were further classified as "administrative", "resource concern", or "stream impact", in increasing order of significance.

Compliance was 100% on two of the three Rules. Two non-complaint practices (95.3% compliance) were observed with respect to adherence to product label requirements. Both resulted in vegetation damage from the direct application of herbicide to open, small wetlands.

South Carolina Forestry Commission (Adams 1996, Jones 2000)

Site-preparation implementation surveys were conducted in South Carolina in 1996 (Adams 1996), and in 2000 (Jones 2000) as follow-up surveys one and two years after harvest in 1997. The 1996 survey was the first in South Carolina for site-preparation operations.

Sites were selected on a county basis, with the number of sites per county proportional to timber harvest volume in the county. Up to seven sites were selected per county. Four categories of landowners oversaw the monitoring sites: industrial and non-industrial private, and state and federal governments.

Each treatment category (e.g., herbicide applications) was evaluated on a pass/fail basis based on responses to a series of yes/no questions in each category. Neither Adams (1996) nor Jones (2000) lists specific questions. Sites were rated inadequate when non-compliance with recommended water quality practices resulted in an evident off-site water quality impact.

In 1996 77 herbicide sites were assessed; 88.3% of these were rated in compliance. The most common BMP violation on the nine non-compliant sites was aerial application to

live surface water. On seven of the sites herbicide had killed regeneration and standing timber that had been left in the streamside management zone after harvest.

Fifty-two different sites that had been harvested in 1997 had herbicide treatments by 1999. Herbicide practices at all 52 sites were rated in compliance.

Southern Group of State Foresters (2002)

State foresters from the Southern states collectively developed a framework for BMP implementation monitoring in 2002 (Southern Group of State Foresters (SGSF) 2002). This framework recommends routine implementation monitoring of a suite of silvicultural practices, including "Forest Chemical Application" (herbicides and fertilization). One impetus for the development of this framework was the lack of a model procedure for implementation monitoring. Significantly different methods were in use across the southern states, with consequent inconsistency among states on "statistical design, reproducibility, and general objectivity" (SGSF 2002:1). These inconsistencies resulted in varying degrees of acceptance of monitoring results by the public and regulatory agencies. Statistical soundness, analytical consistency, among-state comparability, objectivity and technical defensibility are objectives of the framework.

Major features of the framework, as described in SGSF (2002), are given below. The framework is best viewed in the context of the largely non-regulatory approach to dealing with forestry-associated non-point source pollution in the South.

- Monitoring Frequency
    - Statewide monitoring should be undertaken and reported at least every three years.
    - Annual monitoring is generally impractical because of (1) the logistics of locating, visiting and evaluating sites on a statewide basis, (2) lack of significant advantages to justify additional costs, and (3) the number of sites needed to achieve statistical reliability. Monitoring on a three-year cycle is adequate to allow visual observations of on-site problems and timely corrective action.
- Site Selection
    - Must be part of a normal, ongoing silvicultural operation, not in conversion to another land use.
    - Presence of surface water not necessary, although states with proximity restrictions on BMP implementation should select sites using the appropriate criteria.
    - The most recent silvicultural activity must not have been completed more than two years prior to monitoring—because of rapid vegetation re-growth, increased difficulty of access, and reduced evidence of problems over time.
    - Random, stratified random, or randomized cluster statistical design is required for site selection. The population of candidate sites can be identified from aerial survey, tax records, notification logs, or other information sources.

- Sample size should be adequate to estimate implementation within ±5% with a 95% confidence interval.

- Basis for BMP Evaluation and Reporting
  - Individual practices, categories of practices and overall site.
  - Evaluation of categories of practices allows conclusions to be made for stream crossings, roads, etc.
- Scoring Methodology
  - Yes/no for individual practices tallied as a percent, with any significant deviation from practice specifications classified as a "no".
  - The yes/no approach is more repeatable and less subjective than graduated scales for partial implementation or arbitrary "pass/fail" scoring.
- Risk Assessment
  - Evaluate risk to water quality and document significant risk.
  - Attribute risk to non-implementation of specific BMP or category of BMPs.
  - Base risk assessment on existing conditions that have resulted, or likely will result, in measurable and/or significant degradation of water quality (i.e., a standards violation).
- Follow-up Actions
  - Provide participating landowners a copy and explanation of results, with recommendations for any needed remedial actions.
  - Attempt follow-up visits in cases of significant risk, to assure landowner understanding of the recommendations, implementation of remedial action and possible enforcement actions or other liabilities as consequences of inaction.

Washington Timber/Fish/Wildlife Field Implementation Committee (1991)

The most recent BMP implementation survey addressing herbicides was conducted in the summer of 1991; there is no more recent survey (McNaughton 2003).

Sampling was designed to be statistically valid—with a random selection component--to +/-10% accuracy, and with a precision of 90%, both for the overall survey and for each class of forest practice. The three herbicide-related questions addressed (1) buffer adequacy, by presence of dead vegetation, (2) site posting prior to chemical treatment, and (3) compliance with any special conditions associated with the chemical treatment.

Eighteen herbicide applications were assessed, as well as seven applications for fertilizer and insecticide treatments. The results group all 25 applications, and do not separate out herbicide treatments. Results:

- 12% of the applications showed no evidence of buffers on relevant stream types.
- 10 of the 25 operations were posted; it was unknown whether the other 15 were posted.
- 25% of the operations had special conditions; they were all complied with.

Comments on the buffer inadequacies included—

- Map shows buffers. Draws were not buffered and probably not flowing.

- One 50' spot were chemical drifted into RMZ. One place only.
- Possible Type 5 water not completely buffered, but may not have been flowing at time of application.
- Some evidence of slight drift. Some trees show signs of drift in top. Ground level vegetation ok.

The report concluded that--

> Compliance assessment of pesticide and fertilizer applications is non-comprehensive due to the lack of information on stream flow at the time of operations. Specifically, it is not common for type 4 and 5 streams to be verified at the field level to determine if a stream is flowing at the time of application. The nature of insecticides and fertilizer restrict any visual evidence of chemical impacts to the resources.

Table 5 summarizes the implementation monitoring results from the seven states.

Lolo National Forest, Missoula Ranger District Drift Card Reports

In spring and autumn 2002, staff on the Lolo National Forest in western Montana monitored 18 drift card lines—with cards typically at 30' intervals--on five noxious weed projects, for evidence of herbicides applied aerially for noxious weed control (USDA Forest Service 2002a-c). The card lines spanned streamside buffers ranging up to 300' wide. Confirmed initial detections ranged from no detections (out to 300' at 5 lines and 100' at a 100' line) to detections at 270' (3 lines), and 0', 30', 60', 120', 160', 180', 210', 240' (all for 300' lines), and 100' (100' line).

Considerations with respect to the drift card procedure included—

- The need for very careful handling of the cards, because of their sensitivity to moisture. Finger smudges were observed that complicated interpretation of the monitoring results.
- The need for diligent observation by card placement staff for potential confounding effects like collection of dew and drip from vegetation on the cards. Dew could best be observed during card placement and collection, and might otherwise not have been identified.
- Best results are obtained when the cards are erected immediately before spraying, ideally the same day as spraying.

Modeling had indicated that 100' buffers would be adequate to prevent herbicide from reaching stream channels in adverse wind conditions. The wider buffers were for additional protection. "The field monitoring indicates a 100' buffer would have been effective ... "and the 300' buffers were described as possibly too wide "...in non-complex application situations and where the uncertainty factor and possibility for error are low" (USDA Forest Service 2002a and b).

Table 5. Selected Characteristics of Implementation Monitoring of Herbicide BMPs Conducted by Several States.

State	Percent Compli-ance	No. Sites	Random Sites?	Method	Questions
Montana	100	40	Uncertain	5-category rating	Know & comply with regulations governing the storage, handling, application, & disposal of hazardous. Follow all label instructions
Florida	99.5 (217 of 219 actions)	34	Yes	Yes/no	Kept aerial/mist-blown pesticides out of Primary Zone Kept aerial/mist-blown pesticides out of Secondary Zone Applied pesticides according to label Kept aerial applications of herbicides out of SMZ Used properly labeled pesticides for target pests Directed pesticide only onto targeted area Removed pesticide containers from site Located chemical transfer/loading areas outside of the Primary Zone Cleaned spray equipment outside of SMZ Properly disposed of hazardous waste Kept non-wetland pesticides out of wetlands
Georgia	100 (46 actions)	23	Yes	Yes/no; % of acres in compliance	It appears that all State & Federal laws regarding the storage, transportation, handling, application & disposal of all chemicals & containers are followed It appears that chemical drift into sensitive areas has been avoided
Washington	88 (22 of 25 actions)	18	Yes	Yes/no	Is there evidence that all waters were not properly buffered Was the site posted before chemical application Were any special conditions placed on the application? If yes, were they complied with? If no, did it result in damage or potential damage to public resources?
South Carolina	100	52	Yes	Yes/no	Not listed
Arkansas	99	52	Yes	Yes/no	No evidence of leaks, spills or misapplications No evidence of application to SMZ zones
Oregon	98.4 (127 of 129 actions)	units	Yes	3-category rating	Waters of the State protected & label followed Riparian Management Area vegetation protected Vegetation within 10' of specified Waters of the State protected

In 2003 drift cards were similarly placed at 30' intervals on eight lines up to 300' in length as part of the Blue Mountain Winter Range Project (USDA Forest Service 2003c). Detections were identified initially at 270' (1 line) and 180' (2 lines). The other five lines had detections at all cards, although brush was so think along one line that cards were not position at the 0' and 30' distances from the channel. Many of the detections on three of the five lines were "traces". USDA Forest Service (2003c) concluded that the buffers were effective in protecting sensitive areas.

BLM Cottonwood Field Office, 2002 Noxious Weed Treatments

In 2002 the Cottonwood Field Office of USDI BLM treated over 540 acres in the Lower Snake, Lower Salmon, Clearwater and Little Salmon sub-basins in Idaho for noxious and other weed control (USDI BLM 2002). Two hundred ninety-five acres received aerial application; the remaining 245.87 acres were treated by ground techniques. Tordon (picloram)/2,4-D was the primary herbicide applied, although some acreage was treated by Rodeo (glyphosate) and Transline (clopyralid).

USDI BLM (2002) describes the implementation monitoring relevant to BMPs for these projects as—

> A pesticide application record was completed at each project to record weather conditions, amount of herbicide applied and other relevant information. At the completion of all high priority projects a noxious weed post treatment evaluation was completed to reflect the success of control and to assess any off-target issues. Post treatment monitoring continues to show standard project criteria to be adequate for prevention of off site movement and/or non-target issues.
>
> Specific to record keeping in the Cottonwood Field Office, in addition to the requirement to fill out a pesticide application record, weekly checks were made by supervisory personnel to assure complete recording of required information, and filing records appropriately. In addition, spot checks of crews were made to assure they were complying with the requirements of Appendix D of the 2002 BA [BMPs] such as the presence of spill kits in the vehicles, only transporting enough chemical for the project/ days work from the storage area, proper safety equipment, implementation of buffers, etc.

Summary of Interview and Questionnaire Results

This section summarizes comments on herbicide BMP implementation obtained during interviews with 60 individuals and questionnaire responses on herbicide BMP implementation and implementation monitoring. The interview comments are grouped initially by agency, to document the scope of implementation monitoring. Comments on specific implementation topics then follow (e.g., implementation issues). The topics in the questionnaire response summary are the questions asked in the survey.

Comprehensive transcriptions from the interviews and the entirety of each questionnaire response are listed in Appendices A and B; this section summarizes information relevant

to BMP implementation. In the following text, the source of the information/opinion is listed at the end of each paragraph(s). The interview comments and survey responses are not drawn from a scientifically derived sample. They should not be considered a comprehensive depiction of the herbicide BMP implementation activities, opinions, or policies of any institution.

Interviews

State Forestry Department Implementation Monitoring

California—California does not have a systematic program for herbicide BMP implementation monitoring. The North Coast Regional Water Quality Control Board has sponsored effectiveness monitoring that is described in the Effectiveness chapter of this report (P. Caffereta and C. Brandow, California Department of Forestry and Fire Protection).

Colorado—NRCS in Colorado has been involved with the establishment of many miles of streamside buffers in agricultural areas; Colorado's non-point source program has not been involved (L. Fisher, CO Water Quality Control Division). There is no known implementation monitoring for herbicide BMPs in forest or rangelands conducted by the state of Colorado (P. Schwolert, Coloardo Dept. Forestry).

Maryland--The last implementation survey was 6-7 years ago. It's not known whether herbicides were included. Monitoring is planned for Chesapeake Bay forestlands to "double check" implementation of BMPs. Regulations, implementation and effectiveness of herbicide practices are satisfactory; buffer widths are adequate (A. Strang, Maryland Forest Service).

Montana—The Forestry Division, Montana Department of Natural Resources and Conservation, monitors BMP implementation every two years with interagency teams. Pesticides are usually addressed. Relevant documentation was sent (C. Walker, FS).

North Carolina—Focus of implementation monitoring has been on harvesting, not site preparation activities like herbicide treatments. The compliance/implementation monitoring groups site preparation activities together and does not break out herbicides (M. Gueth, North Carolina, Div. Forest Resources).

South Carolina—In the early 90's in the South harvesting was the focus of implementation monitoring; there was very little work on site preparation. In South Carolina more recent compliance monitoring identified some instances of overflying into buffers during site preparation activities (e.g., herbicide treatment) (T. Adams, South Carolina Forest Commission).

Virginia--Semi-annual field audits for implementation and effectiveness typically do not address herbicides. The general utility of buffers is recognized, and a major program is

underway to increase buffer mileage around Chesapeake Bay (S. Austin, Virginia Dept. Forestry).

USDA Forest Service

Humboldt-Toiyabe National Forest (Nevada)—Not aware of implementation (or effectiveness) monitoring of herbicides on the Forest (J. Bergman, FS).

Payette National Forest (Idaho)—Post-treatment monitoring incorporates ocular observations of the condition of target and non-target vegetation. This monitoring is relatively cursory and subjective. The treatments themselves are typically on scattered weed infestations in small areas with backpacks and handguns, and never aerial applications (P. Grinde, FS).

Salmon-Challis National Forest (Idaho)—The Forest has done little monitoring and no monitoring data are available (B. Rose, FS).

Southwest Region, USDA Forest Service—Herbicide BMPs are implemented, although comprehensive implementation or effectiveness monitoring is not done (D. Parker, FS).

Stanislaus National Forest (California)--Post-treatment visual inspection of live vs. dead vegetation is the major means of determining proper buffer implementation. Contract inspectors and silviculturalists are part of the team evaluating buffer implementation and effectiveness on an on-going basis throughout the duration of herbicide projects. Inspection during application is critical. There is no formally prescribed methodology for post-treatment inspection (J. Frazier, FS).

A multi-step process is used to locate live water prior to aerial herbicide treatments. In the planning phase, months before herbicide application, maps, databases and air photos are used to locate all theoretical water bodies. Several months before treatment (e.g., in autumn for spring application) field crews walk the unit(s) mapping surface water locations. Dry sites that could be wet in the spring are flagged. Immediately prior to treatment another on-the-ground search is made for live water, and all potential live water locations are verified (J. Frazier, FS).

Implementation Issues

Potential live water-related problems—

- Concentrations of water bodies (e.g., springs) over a small treatment unit could be flagged individually but may be too close together to allow effective buffering individually for aerial treatment. In this situation the entire unit could be left untreated (J. Frazier, FS).
- In reforestation applications snags can cause the aircraft pilot to fly higher than prescribed, thereby increasing drift, potentially into buffer zones. This problem can be addressed by mapping of snags prior to treatment and/or widening the buffer (J. Frazier, FS).

Timing of monitoring—A basic difficulty is visiting a site long after treatment; don't know what was/wasn't done on the ground (J. Greis, FS).

Interpretation of monitoring results—Statistical results from compliance surveys can be misleading, especially when survey isn't designed for site prep activities but site prep (e.g., herbicides) is included anyway (T. Adams, South Carolina Forestry Commission).

General Implementation

US EPA

Chemical management BMPs as a group are the most closely adhered to of any BMPs (this opinion is based primarily on larger operations, with limited experience talking with smaller operators). State forestry staff believe herbicide BMPs are implemented, and implemented better than other types of BMPs. Traditional compliance surveys, however, may not provide particularly useful information. In general, both the implementation and effectiveness of herbicide BMPs are adequate, at least at the industry level (C. Solloway, US EPA).

Questionnaire Responses

Selection of Monitoring Projects

No particular reasons stand out among the questionnaire responses for identifying projects for implementation monitoring. Areas with sensitive resources, random selection, environmental analysis process, plus several other reasons are given, in almost equal frequency, as reasons for determining projects for implementation monitoring. A statistical component is used in project selection by some respondents, but most do not use statistics. Two respondents monitor all projects. Less than one-quarter of the respondents include a quality assurance/control component in the project selection process.

Weaknesses in Project Selection Process

Almost one-quarter of the respondents state that weaknesses in the site selection process for implementation monitoring exist. One weakness cited is the lack of a statistical component in site selection.

Implementation Assessment Methods

Visual inspection is the primary method used to assure correct helicopter flight path and height, buffer width and nozzle type and orientation for aerial treatments, although other methods used include spray cards and post-treatment monitoring (both for buffer width) and reliance on the oversight of the project supervisory forester (for nozzle type/orientation). For ground applications, observation of dead or dying vegetation is the

primary means of assessing buffer width implementation, although visual inspection of colorant added to the chemical application mix is mentioned by two respondents.

Aerial inspection and walking stream channels are the two primary ways of identifying the location of live water. And on-site gauging is the main method for determining correct implementation of weather criteria.

Direct inspection, reliance on the project's supervisory forester, and applicator liability and guarantees are ways cited to assure correct aerial herbicide application rates. Direct inspection and forester oversight are also used to assess implementation of chemical storage, handling and transport practices for both aerial and ground applications.

Weaknesses in Implementation Monitoring

Identification of live water is the weakness most often cited in implementation monitoring.

Discussion and Interpretation

From the information collected in this investigation, little direct monitoring of herbicide BMP implementation appears to occur except by states, and particularly southern states. The state monitoring typically incorporates yes/no answers to relevant questions such as "Kept aerial/mist-blown pesticides out of Primary [streamside] Zone?" Monitoring methods include the observation of dead or dying vegetation in buffer zones and other after-the-fact observations. The reports do not explicitly describe how determinations on implementation are made. For instance, specifically how it is known that aerial/mist-blown pesticides are kept out of streamside zones is not stated. Reliance on the project's supervisory forester is another method for implementation monitoring. Most states reported that implementation was high and often in the 90%+ range.

The use of buffer spray cards or observation of colorant mixed with herbicides provide a near-real time capability for influencing herbicide operations. These later procedures were seldom mentioned however, either in state implementation monitoring reports or in interviews or questionnaire responses. Spray card monitoring, or similar procedures, are requirements for aerial spraying in recent Biological Opinions for herbicide projects on federal lands in the northwest (see Effectiveness section).

It is not clear that the complete spectrum of herbicide BMPs are assessed in the state implementation monitoring programs, or other monitoring for that matter. This is because the monitoring is typically conducted months after treatment, with observation of dead vegetation a primary mode of assessment. Assessment of vegetation condition may be a reasonable approach to assess buffer implementation, but other BMPs like proper application rate, choice of herbicide, etc. are not necessarily addressed.

Drift or direct spray onto live water was the most-cited implementation problem in the state reports, the interviews and the questionnaire responses. Typically, live water is

identified from aerial surveys immediately before herbicide application. This may not be the best approach, especially where dense vegetation can hide springs or other small water courses. The Stanislaus National Forest follows a more comprehensive procedure incorporating—

- Office identification of candidate live water sites (from maps, aerial photos and databases).
- On-the-ground walking of the treatment unit--several months prior to application--with the specific aim of locating, mapping and flagging potential live water.
- Flagging of dry sites that could be wet during treatment.
- A second on-the-ground inspection immediately before treatment.

Other buffer-related implementation issues are the density of water bodies and causes of inadvertently high application heights. High concentration of water bodies over a small area may be impractical to treat from a water quality perspective because adequate buffering would result in candidate treatment areas too small and/or too impractically shaped to be effectively treated from the air. Snags or other obstacles in the treatment zone near buffers can cause an increase in aircraft height, which results in drift over a broader geographical area, potentially into buffers or onto surface waters. Mapping of potential obstacles, and widening of buffers where they occur can limit this potential problem.

Water quality monitoring, typically conducted concurrent with and after herbicide treatment, indirectly gauges implementation to the extent that water contamination can be due to either failings in BMP implementation or effectiveness. If contamination is identified, retrospective analysis can identify implementation shortcomings. Alternatively, if herbicide concentrations in surface waters are deemed within acceptable limits, the implication is that BMPs were implemented. This is not a tight cause-effect verification of implementation because factors other than implementation could contribute to or cause the low surface water concentrations (e.g., inadequate chemistry monitoring).

HERBICIDE BMP EFFECTIVENESS

BMP effectiveness is partially contingent upon the criteria designated to assess effectiveness. This chapter includes discussion of water quality standards and other assessment criteria, other issues in effectiveness assessment and techniques for monitoring herbicide BMP effectiveness. The chapter concludes with summaries of the interview and questionnaire responses and literature review, and interpretation of these results.

Water Quality Criteria and BMP Effectiveness

BMP effectiveness characterizes how well water quality is protected by implementing BMP(s). Protection of water quality is related directly to the operational definition(s) of water quality objectives, criteria or standards that can vary by state, sub-region or locality. Herbicide product labels, forest practice rules, and potentially other legal directives are gauges for evaluating the effectiveness of BMPs for protecting water quality.

Water quality standards typically describe narrative or numeric objectives. For instance, standards for the Lahontan Regional Water Quality Control Board in California (State of California 1994: 3-5 to 3-6) state (in part):

> Pesticide concentrations, individually or collectively, shall not exceed the lowest detectable levels, using the most recent detection procedures available. There shall not be an increase in pesticide concentrations found in bottom sediments. There shall be no detectable increase in bioaccumulation of pesticides in aquatic life.

This "no detection" standard compares to the biological/beneficial use-based water quality objectives for the geographically adjacent Central Valley Board (State of California 1998: III-6):

- Where more than one objective may be applicable, the most stringent objective applies.
- No individual pesticide or combination of pesticides shall be present in concentrations that adversely affect beneficial uses.
- Discharges shall not result in pesticide concentrations in bottom sediments or aquatic life that adversely affect beneficial uses.
- Total identifiable persistent chlorinated hydrocarbon pesticides shall not be present in the water column at concentrations detectable within the accuracy of analytical methods approved by the Environmental Protection Agency or the Executive Officer.
- Pesticide concentrations shall not exceed those allowable by applicable anti-degradation policies (in State Water Resources Control Board Resolution No. 68-16 and 40 C.F.R. Section 131.12.).
- Pesticide concentrations shall not exceed the lowest levels technically and economically achievable.

In practice, "concentrations that adversely affect beneficial uses" are often quantified by first identifying beneficial uses for the project area and then determining applicable thresholds for adversely affecting those beneficial uses. For example, the Stanislaus

National Forest and the State of California identified downstream domestic use, agriculture and freshwater habitat as beneficial uses for land burned by wildfire in the early 1990s (USDA Forest Service 2003b). The Forest further determined US EPA Health Advisories to be the most stringent numerical water quality objective applicable to the project.

The Stanislaus Forest example exemplifies a common sequential approach to effectiveness assessment: (1) identify relevant water quality criteria based upon local beneficial uses of water, (2) quantify the criteria (if needed), (3) monitor surface or ground water adjacent to herbicide treatment areas (typically for water column chemistry) and (4) compare the monitoring results to the quantified criteria to determine BMP effectiveness. This approach, which is by far the most common identified in the literature review, questionnaire responses, and interviews, does not distinguish among BMPs, rather it "lumps" all practices together. Consequently, effectiveness of specific BMPs is seldom addressed. The few instances identified in this investigation where specific BMPs were assessed occurred when water column sampling identified problems. The problems were then tracked back to specific BMPs.

Issues in Effectiveness Assessment

In situations where aquatic habitat is the primary or sole use, numeric criteria are developed from toxicological studies assessing chronic and acute effects on sensitive biota (e.g., Oregon Dept. Forestry 1997, Norris and Dost 1992). These studies can produce differing results, so completely deterministic definitions of numerical criteria may not be possible, particularly as scientific advances uncover potential biological effects that previously were unknown, unanticipated, or non-quantifiable. Sub-lethal effects on aquatic biota are a current example of the uncertainty that can foster conservative decisions about BMP effectiveness.

A BMP or group of BMPs may be "effective" under one criteria or standard, but not effective under another criteria/standard. In this sense, "effectiveness" depends on how high the "bar" is set, particularly for narrative criteria that may incorporate some level of subjective interpretation. For instance, monitoring results from the Stanislaus National Forest in California typically identify positive detections of some herbicides that are below biologically-based criteria in effect for the Central Valley Water Quality Control Board in California. Those same detections would violate the "no detection" criteria for the Lahontan Board.

Differing, and potentially conflicting, criteria may exist. For instance, Forest Practice Rules, water quality standards, and product label directives may all constitute applicable requirements. The Practice Rules may be more restrictive in some situations, while water quality criteria (or EPA-approved labels) may be more restrictive in others. In the following sections BMPs are considered effective if all applicable requirements are met, including the most restrictive criteria.

BMP effectiveness also has a site-specific aspect. For agricultural BMPs, Hatfield et al. (2001) noted that BMPs for reducing nonpoint source pollution have generated a variety of results, and that by implication assessment of BMP effectiveness is not necessarily straightforward. Variation in effectiveness is largely due to the spectrum of combinations of watershed and local-scale physical factors (e.g., soil texture, depth, structure, organic matter content and water-holding capacity; precipitation; slope; herbicide application rate) that change temporally at varying rates, thereby affecting BMP effectiveness. These authors argue for the need to evolve a revised philosophy of BMP's "that includes an aspect of spatial and temporal variation. When we begin to understand this process we will be able to show the impact of applying BMP's on environmental quality." Ramifications of this philosophy include the need to (1) tailor BMPs to individual watersheds, and (2) link BMPs that address application rates, and the timing and amount of water movement through a watershed to garner maximum benefit. "We have an understanding of the basic processes controlling the movement of water and the affect [sic] of the BMP on soil water. What we lack is how these practices interact across the landscape to produce variation in leaching or surface runoff amounts" (Hatfield et al. 2001).

Techniques for Monitoring BMP Effectiveness

Although water column sampling is a common diagnostic tool for BMP assessment, an alternative assessment method, especially for biologically-based water quality criteria, is bio-assessment. There are pros and cons for both bio-assessment and water column sampling. Elevated herbicide concentrations may be fleeting and persist for only a few hours or less, commonly concurrent with rainfall-runoff events. These episodes can be logistically difficult to sample for water chemistry manually or relatively costly to sample with automated sampling devices. Costs of water sample analysis also can be prohibitive. And last, links between water column chemical concentrations and biotic ramifications are not always well understood, particularly at the typically low concentrations that could be associated with sub-lethal effects.

Bio-assessment ideally directly monitors sensitive biota and has been described as a better indicator of ecosystem response to perturbation. The directness of bio-assessment can reduce subjectivity associated with linking water column sampling results to biotic responses. Bio-assessment can also be less expensive and in some ways easier to implement than water column sampling (Shepard 2003, Vowell 2003). Bio-assessment can be temporally less constrained than water column sampling. Because organisms presumably integrate effects over time, the criticality of sampling at the peak herbicide concentration is bypassed and the sampling "window" for bio-assessment is wider than for water column sampling.

Bio-assessment is not without it's criticisms. Costs may not be less than for water column sampling (Frazier 2003). Procedures for bio-assessment are less standardized compared to water chemistry sampling procedures; more of bio-assessment procedures would be needed for routine use in operational monitoring (Paul 2003). The sensitivity of organisms to herbicides is a key component of bio-assessment; short-lived macro-

invertebrates common to some bio-assessment approaches may not be good indicators of herbicide effects. Sub-lethal effects on other, potentially more sensitive, biota may not be evident at the time of the bio-assessment. Caution is also needed to assure that "false positives" do not confound results by indicating impacts that may be due to some non-herbicide cause. Bio-assessment traditionally also requires control-treatment or before-after pairing of sample collection that effectively doubles the time and effort required.

In summary, assessment of BMP effectiveness is not necessarily straightforward. Some of the ambiguities in the following sections on effectiveness studies and questionnaire and interview results may reflect this.

Summary of Interview Comments

This section summarizes comments on herbicide BMP effectiveness obtained during interviews with 60 individuals; comprehensive transcriptions from the interviews are given in Appendices A. The interview comments are best interpreted together with information in other sections of this chapter. For instance, there are relatively few comments from federal land management agencies on results of effectiveness monitoring. The questionnaire results and the case study examples of effectiveness monitoring by federal agencies augment the interview comments.

The interview comments, and questionnaire responses summarized in the next section, are not drawn from a scientifically derived sample. They should not be considered a comprehensive depiction of the herbicide BMP implementation activities, opinions, or policies of any institution. In the following text, the source of the information/opinion is listed at the end of the relevant paragraph(s).

General Effectiveness

Regulatory agencies

BMPs are not effective in meeting the 0-detection standard of California's Lahontan Regional Water Quality Control Board. This is shown by the common occurrence of positive detections of most herbicides in effectiveness monitoring. There is a very high probability of herbicides reaching State waters in urban, forestry and noxious weed applications. (T. Suk, Calif. Lahontan Water Quality Board)

Herbicide BMP effectiveness is uncertain because NOAA does not get monitoring reports they ask for. Monitoring is a critical tool for assessing effectiveness; without field monitoring effectiveness is unknown. Without multi-tiered monitoring of soils and water, and without more systematic procedures for buffer width determination, uncertainty is high about the actual fate (e.g., concentration, persistence) of chemicals in water. There are also uncertainties about how best to monitor. Follow-up monitoring is also needed to assess the adequacy of initial monitoring procedures/approaches. (R. Anderson, NOAA)

Industry

Weyerhaeuser Company in Washington does not monitor water quality because studies in Oregon and Washington showed the general effectiveness of buffers narrower than buffers currently in use. Pilots also err on the conservative side (T. Terry, Weyerhaeuser Company).

Herbicide levels in surface waters are ephemeral, lasting days or a few months at most, and they are several orders of magnitude below biologically harmful concentrations (J. Shepard, NCASI).

A paired watershed study in east Texas is monitoring the effectiveness of BMPs. This project is in progress and comprehensive results are not yet available although preliminary water column monitoring detected low concentrations of glyphosate and imazapyr in many samples (see TexIS section in "OTHER STUDIES" below) (J. Shepard, National Council for Air and Stream Improvement).

Research

In the southern US, BMPs are effective when properly applied, although accidents can happen (J. Michael, FS Research).

USDA FS

Water quality is not an issue re herbicides in the Rocky Mountain region of the USDA Forest Service; most Rocky Mountain region herbicide treatments are away from water (T. McClure, FS).

BMP adequacy depends upon the chemical. Would be great to have more site-specific buffer prescriptions, but the science isn't currently adequate (E. Monnig, FS).

State Forestry and Agriculture Department Effectiveness Monitoring

California

The California Department of Forestry and Fire Protection does not oversee herbicide application on forest and rangelands; herbicides are under the jurisdiction of the Department of Pesticide Regulation (DPR) (P. Caffereta and C. Brandow, both California Dept. Forestry and Fire Protection). The DPR and the North Coast Regional Water Quality Control Board addressed herbicides in the north coastal region of California. Effectiveness monitoring is described below in sections entitled California Department of Pesticide Regulation and North Coast Regional Water Quality Control Board – California.

Colorado

NRCS in Colorado has been involved with the establishment of many miles of streamside buffers in agricultural areas; Colorado's non-point source program has not been involved (L. Fisher, CO Water Quality Control Division). There is no known effectiveness monitoring for herbicide BMPs in forest or rangelands conducted by the state of Colorado (P. Schwolert, Coloardo Dept. Forestry).

Florida

Bio-assessment, with micro-invertebrates, has been tested on Florida streams by comparing samples of biota before and after herbicide application. Although the post-treatment sample collection was a couple of months after herbicide application, the intent was to sample after a couple of rainfall-runoff events but still within the half-lives of the herbicides. This approach addresses actual impairment of aquatic biota, rather than water column chemical concentrations. Any concentration spike associated with runoff would be missed, but presumably the organisms sampled integrate effects over time, thereby incorporating any biological effects of concentration spikes. Bio-assessment is an effective monitoring tool. It is less expensive and in some ways easier than traditional water column monitoring. Bio-assessment provides much more information than water column monitoring (J. Vowell, Florida Div. Forestry).

Maryland

Labels are explicit. By following label instructions there will be no water quality impact (S. Koehn, Maryland State Forester). Regulations, implementation and effectiveness of herbicide practices are satisfactory; buffer widths are adequate (A. Strang, Maryland Forest Service).

Montana

Herbicide BMPs for agriculture are effective in protecting water quality if they are properly implemented, including the development of treatment plans and taking account of envionrmental considerations. Buffer effectiveness is monitored on 20-30 projects annually, by searching for effects on non-target vegetation. No chemistry sampling is conducted, although some groundwater testing may occur. Good communication with applicators and comprehensive review of project reports also address effectiveness. (D. Burch, Montana Dept. of Ag.)

Oregon

A 2000 BMP effectiveness study is the most recent effectiveness activity undertaken by the state of Oregon. This report specifies Oregon's current perspective on effectiveness. It was preceded by a monitoring study in 1992 (J. Cathcart, Oregon Dept. Forestry).

Virginia

Labels are explicit. By following label instructions there will be no water quality impact (J. Garner). Herbicides are not an issue; sediment is. Semi-annual field audits for implementation and effectiveness typically do not address herbicides. The general utility of buffers is recognized, and a major program is underway to increase buffer mileage around Chesapeake Bay (S. Austin, Virginia Dept. Forestry).

Washington

The state of Washington does not currently monitor herbicide BMP effectiveness, largely because of the logistical complexities associated with timely stream sampling. Also, results from assessments in the early 1990s and late 1980s identified non-detectable or trace amounts of herbicides from direct deposition onto unseen water courses. BMPs are implemented with the belief that little herbicide reaches streams. Currently, buffer widths are wider than required (R. Auldes, Washington Dept. Natural Resources). A formal workplan is, however, in place calling for herbicide monitoring to start in 2007, with funding at $150,000/year for 6 years (G. McNaughton, Washington Forest Practices).

Federal Agency Effectiveness Monitoring

Payette National Forest

Post-treatment monitoring incorporates ocular observations of the condition of target and non-target vegetation. This monitoring is relatively cursory and subjective. The treatments themselves are typically on scattered weed infestations in small areas with backpacks and handguns, and never aerial applications (P. Grinde, FS).

Southwest Region, USDA Forest Service

Herbicide BMPs are implemented, although comprehensive implementation or effectiveness monitoring is not done (D. Parker, FS).

Salmon-Challis National Forest

The Forest has done little monitoring and no monitoring data are available (B. Rose, FS).

Modeling

Modifications of the AgDrift drift deposition model have been developed specifically for forestry. They include the addition of forest buffers, the capability to simulate uneven terrain, and a more realistic simulation of herbicide droplet dissipation (J. Shepard, National Council for Air and Stream Improvement).

Ability to crudely model drift and direct spray is available. However, modeling of runoff across buffers is less advanced, partly because of the multitude of site-specific, micro-scale factors influencing runoff (e.g., a 100' buffer with a modest clay depression running

through it won't be very effective; on other hand a 10' loose loam buffer with no depression can effectively reduce runoff). AgDrift, and similar models, aren't good for ground application (P. Durkin, Syracuse Environmental Research Associates).

Bio-assessment

Bio-assessment can be a useful tool for assessing effectiveness. If biotic richness, diversity, etc. are similar before and after treatment, a strong argument is made that the practices work. Bio-assessment is also generally less expensive than water column sampling. However, are the organisms really sensitive to herbicides (J. Shepard, National Council for Air and Stream Improvement)?

The Central Valley Water Quality Control Board, the agency that sets water quality standards in the jurisdiction of the Stanislaus National Forest, has not mentioned bio-assessment as an effectiveness monitoring tool. Consequently, the Forest relies on traditional water column sampling for chemical analysis. Bio-assessment may not be cheaper than water column sampling, and bio-assessment sample analyses contracted for other purposes have had long turn around times. Results from bio-assessment would presumably not be available in anywhere near a real-time basis (J. Frazier, FS).

Organisms are a better indicator of real ecosystem impairment than water column concentrations (J. Vowell, Florida Div. Forestry).

Bio-assessment procedures are less standardized than water column sampling. Success in Oregon with water column monitoring implies that Oregon is likely to stay with water column sampling for any future herbicide monitoring (J. Paul, Oregon Dept. Forestry).

See also Florida Implementation monitoring for further comments on bio-assessment.

Historical Perspective

An historical perspective on broad improvements in water quality is needed comparing the current status with conditions before any BMP implementation. Some of the more toxic products are no longer legal. Other products are used at lower rates than in the past. Understanding of the fate and effects of herbicides is much better now. Don't underestimate progress (R. Lee, BLM).

Effectiveness Issues

Timing of buffer delineation

In the southern United States SMZs are often delineated--based on the observed presence of water--in autumn when the weather cools, leaves have fallen and visibility through the riparian forest is better than in summer. But autumn is often end of multi-month drought, which reduces surface water flows. Timber is harvested after SMZ delineation. The harvesting reduces evapotranspiration and therefore increases streamflow. By spring,

when herbicides are applied, the expanse of water is greater, vis-à-vis the autumn buffer delineation, from the combination of increased evapotranspiration (from harvest) and winter precipitation. Consequently, the buffers may be too narrow. BMPs could be improved to correct this problem (J. Michael, FS Research).

Questionable relevancy of some fate/transport research

Many herbicide fate and transport studies were done concurrent with US EPA's initial herbicide registration process. For some chemicals this was years ago. At that time uncertainty about maximum application rates for the "new" chemicals resulted in rates used in the fate and transport studies that in retrospect were too high (e.g., 3 or 4 times the currently allowable application rate). The results of those early fate and transport studies still showed chemical concentrations in streams to be considerably below Health Advisory levels and toxicological triggers, implying low risk even at elevated application rates (J. Michael, FS Research).

Compliance and effectiveness "inequities"

Compliance and effectiveness are somewhat in the eye of the beholder; what's compliant to one person may not be to another. In Maine, for instance, local authorities set standards; practices that are effective in one political jurisdiction may not be in an adjacent jurisdiction with similar geomorphology, soils, and climate (J. Michael, FS Research).

Ignorance of water quality standards

Herbicide applicators follow product label direction, seemingly with no knowledge of water quality standards. Applicators think that by following label direction they are doing fine (T. Suk, Calif. Lahontan Water Quality Control Board).

Competing factors

Long-lived herbicides are good from the perspective of controlling noxious weeds but are bad from a water quality standpoint (P. Grinde, FS).

Scale of treatments

Concern that on the scale of the entire Columbia River basin, FS noxious weed applications are probably trivial compared to the scale of applications on private lands. Implication [not directly stated by interviewee] is that restrictions on FS may make little difference to health of aquatic biota in comparison to the scope and scale of relatively unregulated private land herbicide treatments (P. Grinde, FS).

Bigger Picture—Erosion/sedimentation and Herbicide Effects

Erosion and sedimentation are the biggest water quality problems worldwide. Herbicide water chemistry impacts are ephemeral (lasting a few hours at most), and considerably below 48- or 96-hr toxicological triggers. Keeping sediment out of water is the real issue. Sedimentation rates associated with herbicides are close to background rates whereas mechanical alternatives to herbicides can produce 20 to 400% more sediment than observed on paired sites that were site-prepared with herbicides (J. Michael, FS Research).

Summary of Questionnaire Responses

Thirteen individuals or organizations responded to the questionnaire. Not all of the respondents answered all of the questions. The responses are numerically summarized in Appendix C and the verbatim responses are listed in Appendix B. This section summarizes the responses in narrative form. Only questions without a large percentage of blank answers are summarized below.

Herbicide Application

Respondents apply herbicides primarily for reforestation purposes, for control of noxious weeds, or both. "Site release" and "post thinning hardwood control" are two other less common reasons given for herbicide treatment.

A variety of chemicals are used by the respondents, although over 60% of the respondents use glyphosate, and over one-third use hexazinone, triclopyr, clopyralid or imazapyr. Backpack, helicopter, and ground vehicle are the primary means of herbicide application. No respondent reported using fixed wing aircraft. Over three-quarters of the respondents apply herbicide in liquid form, and over half use pellets.

Effectiveness Monitoring

Site selection

A variety of criteria are listed by the respondents for site selection for effectiveness monitoring. They include random stratification by beneficial use, accessibility by drill rig and number of major drainages in the project area—both for groundwater monitoring, monitoring plans, accessibility, locations to capture effects from more than one unit (and conversely smaller order streams), and risk assessment/likelihood of detection. Risk assessment/likelihood of detection is the most-cited criterion.

Monitoring methods

Water column sampling and observation of effects on non-target vegetation are the two most-cited methods of determining effectiveness.

Trend monitoring

The respondents report that effectiveness monitoring is repeated through time if treatments are repeated at the same site. The question on this topic may have not been completely clear in that it does not distinguish between repeat effectiveness monitoring with and without new treatment at a given site.

Indicators of BMP effectiveness

Few respondents identified good indicators of BMP effectiveness; those that did listed water quality objectives, off-target vegetation and biological indices.

Difficult-to-assess BMPs

Few respondents also identified difficult BMPs to assess for effectiveness; those that did listed spray drift modeling, inter-organizational coordination, and prohibition of hexazinone in groundwater.

Implementation vs. effectiveness

When asked to distinguish between lack of implementation and BMP ineffectiveness as contributors to water quality problems, no respondent listed actual ineffectiveness as the cause. Lack of implementation and lack of knowledge of herbicide dynamics were the causes listed.

Causes of ineffectiveness

Of the three responses to causes of BMP ineffectiveness, two mentioned inadequate training and one listed potential concurrent treatment on nearby private land.

Additional BMPs

Over 30% of the respondents do not believe additional BMPs are needed to protect water quality. The three situations listed as potentially requiring additional BMPs are: (1) noxious weed treatments within or adjacent to water bodies, (2) sub-lethal effects to aquatic species, and (3) only if existing BMPs, especially buffers, are not implemented well.

Knowledge gaps

No single predominating information or knowledge gap is listed by the respondents. Areas needing improved understanding are adjuvant toxicities, complex terrain effects, half-boom effectiveness, runoff from storm events, foliage interception and herbicide toxicities at minute levels.

Examples of Effectiveness Studies

Only a few documents were identified that address the effectiveness of specific herbicide BMPs for protecting water quality in forest and rangelands. The majority of reports measure water column concentrations of herbicides, typically with control sampling immediately prior to herbicide treatment, and post-treatment sampling. Specific BMPs are seldom mentioned other than buffer widths. Typically, results of water column measurements have been judged to affirm the usefulness of BMPs. Unexpected high concentrations are either not linked to BMPs specifically or are attributed to "accidents".

A summary of specific case studies of effectiveness monitoring follows. Few of these examples are "research grade" studies. Rather most of the examples assess operational herbicide applications within the constraints of existing resources. Information on effectiveness from recent NOAA Biological Opinions for projects in Oregon, Idaho and Montana is also summarized. Because private industry, a major applicator of forest herbicides, is not well otherwise represented in this report, a summary of an industry document on potential limitations of herbicide BMP effectiveness is included.

Washington Department of Ecology

Rashin and Graber (1993) is one of the few known studies directly assessing the effectiveness of herbicide BMPs. This report notes the need to address Washington Forest Practice Rules, relevant water quality standards and product label directives as the basis for assessment of BMP effectiveness. These rules, standards and directives are somewhat open to interpretation and they do not always set numeric criteria for surface water concentrations.

Objectives of the study were to:

- Characterize peak and mean pesticide concentrations in streams subjected to aerial treatment according to established forest practice BMPs
- Determine the effectiveness of BMPs for aerial application for achieving surface water quality standards, meeting provisions of forest practice rules, other state pesticide regulations, and EPA-approved product label directives
- Evaluate factors contributing to pesticide BMP (in)effectiveness
- Assess the efficacy of monitoring procedures for evaluating water quality effects of aerial forest pesticide treatment.

Methods

Intensive water column sampling was undertaken before, during and after helicopter application of pesticides at seven sites in western Washington in 1991. All applicable BMPs were scheduled for implementation. Water sampling was timed to match dormant, early foliar and late foliar vegetation stages. Three siting scenarios were (1) a single stream adjacent or near the spray unit, with no tributaries, (2) a single stream adjacent or near the spray unit, with multiple tributaries, and (3) one or more streams located within the actual spray unit.

Samples were collected, as discrete grab samples, and hand- or automated sampler-composites. Grab samples were collected at ¼, ½, 1, 2, 3, 4, 6, 8, 10, 12 and 24 hours after the estimated time of arrival of stream water from the spray area, plus ½, 4, 10, 24, and 48 hours after completion of spraying, with no adjustment for stream time-of-travel. These sampling frequencies were specified in protocols employed by the Oregon State Department of Forestry and the Washington State Department of Natural Resources at the time of the study. The automated sampling was done at 15-min intervals, composited to 6 and 24-hr samples. A second 24-hr composite sample was routinely collected as well as a third 24-hr composite sample in one case where rainfall runoff occurred soon after spraying. Several runoff samples collected up to 3 ½ week after treatment at four sites supplemented the immediate post-spray sampling. Post-application runoff sampling was not, however, the primary focus of the project. Instead, concentrations during the first 48 hours after treatment were related to aquatic life criteria. Meteorological and stream discharge monitoring, plus direct observation of the spraying, rounded out the data collection procedures.

Glyphosate (Accord), 2,4-D (Weedone LV4), triclopyr (Garlon 4) and imazapyr (Arsenal) were applied to at least two sites per herbicide. Laboratory detection limits, in ppb, were 0.03-0.04 for 2,4-D, 0.20 for glyphosate=0.20; 0.01-0.04 for triclopyr and 0.02 for imazapyr. Treatment units ranged in area from 12 to 105 acres. Five practices were focused on:

- No aerial application of herbicides within Riparian Management Zones
- A 50' buffer along all Type 1, 2, 3 and flowing Type 4 and 5 streams
- Parallel flight paths and use of control agents adjacent to streams
- Reconnaissance over-flight by pilot and landowner prior to application to identify target areas and buffers
- Shut-off of spray devices during turns and over open water.

Results

Detections of all four herbicides were common, and ranged from 41 to 67 percent of all samples collected. Peak concentrations typically occurred within three hours of herbicide application for all herbicides. Rashin and Graber (1993) attributed the detection of herbicide soon after treatment to off-target swath displacement, which was visually observed at some sites, and consequent drift into streams. Spot checks of wind speed documented gusts to 16 km/hr (10 mph) or more, which support the swath displacement hypothesis.

The forester in charge of the project did not identify up to three occurrences of live water that Rashin and Graber (1993) had seen one week prior to application. At one of these sites logging slash potentially obscured the live water using typical surveillance procedures. Improper live water identification, with the consequent direct spray of herbicide, could contribute to detections soon after treatment, although Rashin and Graber (1993) felt that the majority of chemical contamination was due to off-target swath displacement because the timing of the peak surface water concentrations corresponded to the initial deposition of near-stream swaths.

At one site runoff began about 39 hr after treatment. All runoff samples at this site had 2,4-D detections at levels greater than prior to the runoff. These elevated runoff concentrations were attributed to post-rainfall expansion of the effective channel network into areas that were dry during spraying and that therefore had not (appropriately per the BMPs) been buffered.

Glyphosate was also detected in runoff over three weeks after spraying. The cause of this detection was not known.

A final source of surface water detections was potentially subsurface flow through a shallow groundwater system at one site. The shallow groundwater was predicated on streamflow measurements at the top and bottom of the stream reach. Similar measurements would not typically be available in operational projects and therefore the occurrence of shallow groundwater would probably not normally be known to project staff.

The following table shows the percentage of all samples with detections by concentration class, except for the Maximum values, which are in ppb.

Detection Amount (ppb)	**Glyphosate (n=70)**	**Triclopyr (n=44)**	**2,4-D (n=48)**	**Imazapyr (n=12)**
Maximum	7.52	1.37	2.49	1.15
> 1	27	2	6	8
0.5 – 1	13	5	8	33
< 0.5	24	34	40	25
Non-detected	36	59	46	33

BMP Issues

Rashin and Graber (1993) attributed several violations of water quality criteria to ineffective BMPs, as noted above, for instance for application to live water. This reasoning is debatable. If a BMP states that herbicide shall not be applied to surface water, then violation of this BMP would seem to be an implementation failing, not an effectiveness problem. Similarly, application during high winds is also arguably an implementation failing.

Nevertheless, because Rashin and Graber (1993:70,72) stated that "... even the most protective buffers cannot prevent drift of the smallest droplet sizes [and] it is not reasonable to expect that any aerial application of pesticides in the vicinity of surface waters can achieve zero introduction of pesticides to the water ...", any criteria prohibiting drift into live water will probably be violated.

Recommendations and Conclusions

The following recommendations were made--

- Different buffer widths should be employed for upwind vs. downwind applications: 15-25 m for downwind and 70-90 m for upwind. Wider buffers may be needed where spray release height is greater than 6 m (e.g., steeper terrain). The wider buffers would not totally eliminate drift to surface waters.
- Buffer width should also ideally be a function of pesticide toxicity.
- Buffers should be measured as the horizontal distance from the edge of the effective swath to the streambank.
- "Buffer", "effective swath", "drift", "direct entry" and "extended swath" should be clearly defined in the Washington Forest Practice Rules.
- BMPs should include provisions, such as nozzle configuration and operating parameters, to minimize small droplets.
- Consistent in label directives is needed between products, especially with respect to drift avoidance, application equipment and entry to surface waters.
- Information or procedural needs include—
    - More effective procedures for identifying live water at the time of spraying.
    - The feasibility and availability of alternative nozzles and boom/half-boom application systems.

Rashin and Graber (1993) concluded that—

- Except for 2,4-D, "maximum instantaneous and 24-hour herbicide levels found at our monitoring locations were lower than the respective [water quality standard] criteria." Instantaneous concentrations of 2,4-D in a runoff event that produced the 2.49 ppb may have exceeded the criteria.
- Washington Forest Practice Rules were violated by drift onto live waters concurrent with, or immediately after spraying.
- Product label prohibitions to keep Garlon 4 "... out of lakes, ponds or streams", to not apply 2,4-D directly to water, to not use hollow-cone type nozzles that produce fine droplets for 2,4-D application, to avoid drift with Accord (glyphosate) and to not apply Arsenal (imazapyr) directly to water were violated.
- Overspray of small streams that could have mistakenly been assumed to be dry did not contribute greatly to peak downstream herbicide levels. The overspray could, however, have been a source of toxic levels at the point of introduction and could adversely affect the resident aquatic biota.

Oregon State Department of Forestry 2000 (Oregon DOF 2000)

Changes to Oregon's Forest Practice Rules in 1997 necessitated monitoring of the effectiveness of the Rules, specifically for protecting fish-bearing and domestic use streams from unacceptable drift contamination during aerial herbicide treatments. Rule effectiveness was evaluated in a field study conducted in 1997 and 1999 at 26 streams located in the Oregon Coast Range, interior, and western Cascades (Oregon DOF 2000).

Methods

Six herbicides (glyphosate, chlorothalonil, 2,4-D ester, triclopyr, clopyralid, hexazinone and sulfometuron-methyl) were applied to units adjacent to 26 streams ranging in width from 2.5' to 26'. Sixty-foot, no-herbicide buffers were established on all streams. Six water samples were collected 0 to 200' below the downstream unit border, one before treatment, and five collected ¼, 2, 4, 8, and 24 hr after application (including estimated travel time). No effort was made to specifically sample post-treatment runoff. The detection limit for samples collected at 21 of the sites was 1 ppb (for all herbicides), and between 0.04 and 0.5 ppb for samples from the remaining sites. In addition to water column sampling, vegetation was surveyed at 24 riparian areas from 14 randomly-selected harvests, along equally spaced transected located every 100-200' along the length of the riparian zones.

Oregon water quality criteria are biologically-based. Numerical concentration criteria were developed from current toxicological studies for aquatic biota and human health. These criteria, as 24-hr average concentrations, were compared to results of the field monitoring.

Results

No herbicide concentrations were detected above 1 ppb. Detectable concentrations of hexazinone (five samples) and 2,4-D (two samples) were identified from the 110 post-treatment samples collected. Maximum concentrations were 0.9 ppb for hexazinone and 0.14 ppb for 2,4-D. The hexazinone samples with detections were 50% of the post-treatment hexazinone samples collected. The detection concentrations were considerably below the most sensitive criteria cited for hexazinone (2500 ppb for human health) and below the most sensitive criteria identified for 2,4-D (7 ppb for bluegill). No evidence of damage to riparian vegetation was identified from the transect surveys within the 60' buffers mandated by the forest practice rules.

Oregon ODF (2000) concluded that "based on current understanding of the toxicity of commonly used forest pesticides with regard to human health and aquatic biota, ... forest practice rules are effective at protecting water quality during aerial herbicide ... applications on ... fish-bearing and domestic use [streams]." The report authors pointed out that the study results pertain to spray drift; water quality protection on streams without overstory riparian buffers or offset spray boundaries, other stream types, or precipitation induced post-treatment runoff was not assessed.

Recommended next steps include assessment of potential effects over a longer time period--specifically during and immediately after precipitation-induced runoff, water quality protection of small streams without riparian overstory canopies, and incidence of surfactants or "inerts".

Buffer Zone Effectiveness on New York Powerline Rights-of-Way

The Empire State Electric Energy Research Corporation commissioned a 1989-1990 study aimed at—

- Assessing the effect of buffer zone width and vegetation density on herbicide deposition outside treated powerline rights-of-way.
- Field testing the effectiveness of specific buffer strategies in protecting water quality during operational herbicide treatment.
- Determining water quality criteria for protecting aquatic organisms and human health (Environmental Consultants, Inc. 1991).

Results of investigation of the first two objectives are summarized here.

Buffer Zone Width and Vegetation Density

Powerline right-of-way maintenance requires control of vegetation within the right-of-way. Herbicides have traditionally been used as a control mechanism.

Methods--Field testing near Binghamton New York, in August 1989, evaluated the effect of three variables: (1) distance from treated area, (2) buffer zone vegetation density (high: stem density estimated at > 3000/acre in both treated and buffer zones, medium: estimated 1500-3000 stems/acre in both treated and buffer zones, low: estimated < 1500 stems/acre in both treated and buffer zones, and none: high density in treated zone but no vegetation in adjacent buffer), and (3) spray application method (high-volume stem-foliar and low-volume basal), on spray deposition in buffer zones adjacent to right-of-ways. Dye, not herbicide, was incorporated into the liquid spray. Otherwise operational herbicide application practices were followed. Each treatment was replicated three times at each of four study sites.

Spray was measured on vertical arrays of string located 0, 10, 25, 50, 75 and 100' from the edge of the sprayed area. Each array comprised six strings positioned vertically 1' apart and spanning a 100' distance parallel to the border of the spray area. The stem foliage treatment was made from atop an all-terrain vehicle, with nozzles adjusted to produce a coarse spray under 50 lb/sq inch pressure. The low-volume basal treatment, applied by backpack sprayer, was intended to coat evenly all exposed bark on the lower 18" of each stem.

Results—Dye deposition occurred at all distances from 0 to 100' into the buffer zones, although typically concentrations were an order of magnitude greater at 0' than at 100', and concentrations generally (although not absolutely) decreased with increasing distance into the buffers. Dye deposition in the buffers was not systematically associated with either buffer vegetation density or application type other than a general decrease in dye concentration away from the treatment zone. Contrary to "common sense", dye concentrations in the buffers were not always lower with the basal treatment, and concentrations at all distances into the low density vegetation buffer were greater with the basal treatment.

Among other items, the report concluded:

> Trained field crews that are effectively supervised can achieve safe herbicide applications that do not result in biologically significant direct application or drift of herbicide into vegetated areas more than 25' from the edge of the treated area. This

provides protection for humans using water from, and for aquatic organisms that are in, the areas designed to be protected by the use of buffers of the dimensions found effective in this test when using 2,4-D ester. When herbicides of lower toxicity than 2,4-D ester are used, narrower buffers could be used and still achieve protection.

Where there is no vegetation in the buffer zone adjacent to areas to be treated, treatments other than high-volume, stem-foliage application may be needed to assure safety. (Environmental Consultants, Inc. 1991:III-43)

Buffers and Operational Herbicide Treatment

Water bodies near eight powerline rights-of-way were monitored for picloram, triclopyr, imazapyr or 2,4-D for parts of an 8-month post-treatment period in eastern New York.

Objectives of this study were to determine—

- Effects of buffer zone and application strategy on direct application and drift of herbicide to surface water.
- Effects of buffer zones on herbicide movement to surface water during autumn, early winter and spring following treatment.

Methods—Sites were selected with sandy or loamy soils anticipated to be most likely to allow herbicide leaching to streams. "Selected sites all had the water originating on the right-of-way entering the stream channel within a few feet of the downstream edge of the right-of-way." (Environmental Consultants, Inc. 1991:IV-5) Target stream size was 1-8' wide and 1-8" deep. Buffer widths ranged from 10' to 100' on the eight sites, to mimic public utility commission mandates. Herbicides were applied either by high-volume stem-foliage or low-volume basal treatments, as described in the Buffer Zone Width and Vegetation Density text above.

Sample collection was immediately downstream from the herbicide treatment zones, although some upstream control samples were also collected. Samples collected at 6-hr intervals, by automated sampler, were composited into daily samples starting with herbicide treatment in September 1989. Compositing continued on a daily basis until the stream froze in the winter, and resumed after the spring thaw for one or more 24-day cycles. Not all composite samples were analyzed for herbicide concentration. For the first 24 days after treatment samples analyzed were—

- One pre-spray sample, as a pre-treatment control.
- One treatment day sample.
- One 6-day composite sample for each 6-day period.
- Individual daily samples from any 6-day composite sample having detectable concentrations of herbicide.
- Daily samples (for three days) from the first three significant rainfall events.

For days 25 to freeze-up each 6-day composite sample was analyzed along with component daily samples of any 6-day composite that had detectable herbicide. After spring thaw, 6-day composite samples were analyzed. Detection limits were 1 ppb for imazapyr and 0.3 ppb for 2,4-D, picloram and triclopyr.

Results-- Most of the several hundred samples collected had non-detectable concentrations. Samples with detectable herbicide concentrations (triclopyr, imazapyr and picloram) were collected shortly after application or during the first significant rainfall after treatment. One detection occurred in the spring after autumn treatment. 2,4-D was not detected in quantifiable amounts. The highest single concentrations detected were 0.002 mg/l triclopyr, 0.001 mg/l picloram and 0.006 mg/l imazapyr. Quantifiable detections were made at six of the eight sites.

The report acknowledges that it is unlikely that maximum concentrations were captured because the samples were composited at daily intervals. Consequences of the 24-hr compositing are described as minimal with respect to risk analyses based on continuous exposure for times ranging from 48 to 96 hours.

The report concludes that—

- "The 100' buffer was well tested and achieved the presumed goal of protecting aquatic organisms and human health".
- "The 30' buffer was well tested for basal applications and achieved the presumed goal of protecting aquatic organisms and human health".
- Based on indirect evidence, the 50' buffer for stem foliar application will achieve water quality goals.

Needed BMP improvement--The 50' buffer situation illustrates an improvement needed in BMP implementation. The 50' buffer was established under dry conditions. During periods of heavy rain marshy surface water expanded into the buffer and effectively narrowed it. The report recommends judicious recognition of terrain situations where heavy rainfall can inadvertently reduce buffer width by expanding the effective area of water bodies.

Florida Bioassessment

Vowell (in press) used a bio-assessment approach based on benthic macroinvertebrate sampling to assess the effectiveness of herbicide BMPs in northern Florida. Composite "Stream Condition Index" numerical values based on macroinvertebrate taxa richness, percent diptera, percent dominance, percent filter feeders, number of chironomidae taxa and other metrics were the assessment tool. Samples were collected in February 1996 and July 1998, on reference and treated stream reaches, before and after May 1998 application of imazapyr/triclopyr and hexazinone/sulfometuron-methyl to two test sites on perennial streams. The herbicide was applied for re-forestation purposes by air at a imazapyr/triclopyr site and by ground techniques over planted pines at a hexazinone/sulfometuron-methyl site. The bio-assessments were conducted on three 100-m stream segments for replication of the measurements. The July sampling was timed to be within the half-life of the herbicides, so that the potential for herbicide to still be in the sampled stream reaches was at least moderately high. Water samples were also

collected in July 1998 and analyzed for the presence of imazapyr/triclopyr and hexazinone/sulfometuron-methyl (Vowell in press).

During treatments all applicable BMPs were implemented, including a "Primary Special Management Zone (SMZ)" along the treated stream reaches. The SMZ was a no-treatment zone that ranged in width from 10.6 to 60.9 m, depending on stream width.

The water chemistry analyses did not detect herbicides in any samples, at a detection limit of 0.12 microgram/liter. Similarly, the pre- and post-treatment bio-assessments did not differ significantly; Stream Condition Index values at both sites were in the "excellent" range for all samplings. Vowell (in press) concluded that "the healthy aquatic habitat, plants and organisms observed in the study both before and after the herbicide ... treatments, points to the effectiveness of BMPs - as an overall system of practices - and to the usefulness of bioassessments in making such determinations."

Eldorado National Forest – California

Since autumn 1991 the Eldorado National Forest has treated thousands of acres of conifer plantations for reforestation purposes with glyphosate (Accord and Roundup), triclopyr (Garlon 4) and hexazinone (Velpar L and Pronone 10G). Application was primarily by backpack sprayers for liquid formulations of Accord, Velpar L and Garlon 4, and broadcast spreaders for pelletized Pronone 10 G. In May 2002 clopyralid and glyphosate were applied to control yellow starthistle and triclopyr was applied for conifer release. Both groundwater and surface water monitoring tracked the fate of the herbicides. The following descriptions of the monitoring programs are taken from Fiore (1995) and Boyd (2000). Bakke (2001) summarized all Eldorado National Forest monitoring through 1999 and Carroll (2002) describes monitoring of clopyralid and hexachlorobenzene in 2002.

Monitoring Objectives

Monitoring objectives were to—

- Determine if herbicide moved off-site after application and into water through overland flow, leaching and subsurface flow, or attached to eroding sediment.
- Determine the amount of chemical residue reaching water.
- If residue entered water, determine the persistence of the residue.
- Comply with State water quality guidelines and BMPs as described in the Central Valley Regional Water Quality Control Board Basin Plan.

Water Quality Standards

The applicable state water quality standards are not numerical. The narrative standards are—

- No individual pesticide or combination of pesticides shall be present in concentrations that adversely affect beneficial uses.

- Discharges shall not result in pesticide concentrations in bottom sediments or aquatic life that adversely affect beneficial uses.
- Pesticide concentrations shall not exceed those allowable by applicable anti-degradation policies.
- Waters designated for use as domestic or municipal supply should not contain concentrations of pesticides in excess of the Maximum Contaminant Levels set forth in the California Code of Regulations, Title 22, Division 4, Chapter 15.

Based on several sources, Eldorado Forest staff translated these standards into numerical criteria (ppb) as follows for the three primary herbicides used prior to 2002:

Chemical	FEIS[1]	$LC_{50}/10$	EPA Lifetime Health Advisory
Glyphosate	28-61	5302	700
Hexazinone	11-36	32,000-42,000[3]	200
Triclopyr	40-97	74[4]	NA[5]

[1] Range reflecting "realistic" and "worst case" concentrations estimated in 1989 Regional guidance (Final Environmental Impact Statement: Vegetation Management for Reforestation, 1989, cited in Fiore 1995).
[2] 48-hr LC_{50} for Daphnia magna, for Roundup (Weed Science Society 1989, cited in Fiore 1995).
[3] 96-hr LC_{50} for trout (USDA Forest Service 1984, cited in Fiore 1995).
[4] 96-hr LC_{50} for trout (Weed Science Society 1989, cited in Fiore 1995).
[5] There is no US EPA Health Advisory value for triclopyr. Using the same methodology used for the hexazinone and glyphosate advisories produces a triclopyr advisory value of 180 ppb.

Best Management Practices

Seven BMPs were applied. They mandate pesticide use planning, adherence to product label and other legal requirements, monitoring needs, disposal of pesticide containers and equipment, streamside and wet area protection during spraying, spill contingency planning, and pesticide drift control (see also Appendix F, California). In 1992 buffers ranging in width from 25 to 200' were prescribed, based upon stream class and herbicide (see Table 3 for specific buffer widths).

Monitoring Site Identification

Fiore (1995) provided a comprehensive rational for monitoring site selection aimed at sample collection at locations and times to optimize the probability of herbicide detection. Candidate treatment units were rated with respect to proximity to water, beneficial uses of that water, and herbicide prescription. Units at greater risk of producing detectable concentrations of herbicides typically are—

- Close to sensitive channel segments (e.g., having domestic use, contact recreation, cold water fisheries as beneficial uses).
- Located in or near bedrock contact zones where leachable herbicides can enter shallow aquifers and associated seeps and springs.
- Located at relatively low elevations and treated in the autumn at the onset of the wet season when rainfall (rather than snowfall) can provide the energy and medium for herbicide movement.

- Treated with hexazinone (vs. glyphosate or triclopyr), because of its relatively long persistence and greater mobility than many other herbicides.

Specific monitoring sites were selected considering safe accessibility during storms, higher risk of detectability, close proximity to the most downstream unit in a group of units, and location upstream of private land.

Thirty-nine surface water sites were chosen, and one groundwater site at a developed spring.

Monitoring Schedule and Procedures

Pre-treatment samples were collected prior to herbicide application in 1992 and 1993 at all monitoring sites. Spring and summer-applied glyphosate and triclopyr were monitored during the first significant runoff-producing storm occurring within 90 days of chemical treatment. 1991 monitoring within 48 hr of application showed no detections, therefore 48-hr monitoring was thereafter discontinued for glyphosate and triclopyr. Autumn-applied hexazinone was also sampled during the first significant runoff-producing storm occurring within 90 days of herbicide application. A snowmelt runoff sample was collected at all sites in the spring following autumn herbicide application. Individual grab samples were collected and at more sensitive units 4-hour samples were collected and composited. Hexazinone sample collection was primarily in 1992 and 1993 although samples at one or more sites were collected annually through 2001.

Results

Glyphosate and triclopyr--Pre-treatment and post-treatment glyphosate samples collected in 1992 and 1993 48 hours after application and after the first storm within 90 days of treatment all had no detectable concentrations. Sixty-six samples were collected in 1992 and 1993.

Eleven of 12 post-treatment triclopyr samples collected in 1991 and 1992 had non-detectable concentrations. The one detection, at 82 ppb after the first post-treatment storm, was caused by not establishing a buffer along an ephemeral headwater stream reach. It was hypothesized that runoff associated with the rain storm entrained triclopyr.

Similarly, no glyphosate or triclopyr detections were identified in post-treatment samples (65 for glyphosate and 57 for triclopyr) collected during most years through 2000. Relatively few samples were collected because few rainfall events occur within the 90-day collection window after the spring applications of these herbicides.

Hexazinone surface-water sampling--The first post-treatment runoff-producing storm in autumn 1992 was sampled for hexazinone at 12 sites. No hexazinone was detected. Twenty-five sites were sampled for hexazinone in mid-April and early-June 1993. Eight samples had detectable hexazinone, ranging in concentration from 1.3 to 19 ppb. Eight

sites were sampled either approximately one year after treatment or one year after first detection. Detections at five sites occurred, ranging from 1.1 to 15 ppb.

For the period 1991-2001, 23% of 220 samples collected had non-detectable concentrations. The bulk (over 90%) of the detections were between 1 and 9.9 ppb, with 2% of the samples having concentrations between 10 and 20 ppb. The remaining sample concentrations were below 1 ppb. Detections continued, almost annually, for 8 years through October 2000 at two sites (neither site had quantifiable detections in 2001).

Hexazinone ground-water sampling—Well samples collected at two sites in the early and mid-1990s showed first detection 5 months after application, with the last detection over one year after application. The maximum concentration detected was 1.7 ppb. Leaching of hexazinone was documented to at least 28' below ground surface at one site and movement of hexazinone up to 450' from the application point at the second site.

Clopyralid and Hexachlorobenzene--Preliminary results from monitoring of ground-applied clopyralid identified no detectable concentrations of either chemical (Carroll 2002). The clopyralid was applied in April and May 2002 to control yellow. No-spray buffers ranged in width from 0', for ephemeral streams, to 75' for perennial channels providing water for domestic and municipal purposes. Two monitoring sites were located on streams determined to have the greatest risk of chemicals entering the water and the greatest risk to beneficial uses of that water. The samples were collected after the first major post-application storm within 30 days of herbicide treatment (detection limit = 0.5 ppb for clopyralid and 0.1 ppb for hexachlorobenzene) (Carroll 2002).

California Department of Pesticide Regulation

In response to concerns expressed by members of the Yurok, Karuk and Hupa tribes of northwestern California about potential contamination of drinking water from herbicide treatments on nearby private lands, numerous surface water samples were collected in the late 1990's both immediately downstream of herbicide application sites (site scale), and on larger channels potentially distant from application sites (watershed scale). Approximately 40,631 pounds of active ingredient of 13 herbicides and 19 insecticides were applied within the privately-owned watersheds upstream of locations sampled at the watershed scale.

None of the reports summarized below mention BMPs, other than that the site-scale herbicide applications were made within the label rates. The presumption is therefore that at a minimum product label directives and state rules and practices for herbicide application were in effect prior to the herbicide applications monitored.

Watershed-scale monitoring

One hundred eight water samples were collected by State of California staff or contractors in the Hupa and Karuk Territories at six sites on the Klamath, Trinity and

Scott Rivers, and Elk, Pine and Supply Creek on four occasions between September 1998 and October 1999 (Jones et al. 2000a). Jones et al. (2000a) do not mention the type (aerial/ground), timing or purpose(s) of herbicide applications.

Of the 13 herbicides monitored, several (e.g., 2,4-D, glyphosate, hexazinone and triclopyr) are relevant to BLM and USDA Forest Service projects in the western US. Timing of sample collection was scheduled partially to coordinate with runoff events. The first collection, done under dry conditions in September 1998, served as background. Collections in October 1998 and 1999 sampled storm runoff. Collections in June 1999 corresponded to the end of the heaviest pesticide application season (Jones et al. 2000a).

No detectable concentrations of any herbicides were identified (reliable detection limits ranged from 0.04 to 2.0 ppb). Because this monitoring was at the watershed scale, direct cause-effect linkage between herbicide application and water quality effects is not possible. Several months passed between dry weather application and the first rain, potentially allowing chemical degradation or adsorption to soil. Dilution of streamflow between application and monitoring sites may also have contributed to the lack of positive detections (Jones et al. 2000a).

Site-scale monitoring

Surface waters in the Yurok aboriginal territory in the Klamath River watershed were sampled in April, May, September, and October 1999, and April and May 2000 for atrazine, triclopyr, glyphosate and 2,4-D. Both ground and aerially-treated units were grab sampled using automated sample collection devices. The purpose(s) of the herbicide treatments are not mentioned in the reports describing the water quality monitoring. Detection limits were 0.05, 0.1, 2.0 and 0.1 ppb for atrazine, triclopyr, glyphosate and 2,4-D respectively.

The 1999 spring sample collections, made at four sites during rainfall within two weeks of herbicide application, identified no detectable concentrations of atrazine, triclopyr or 2,4-D (Jones and Wofford 1999). The September/October 1999 sample collections, taken during both application and the first post-application rain-runoff event at three other sites, documented triclopyr concentrations at one site ranging from 0.17 to 0.43 ppb during the runoff. No detections of triclopyr or glyphosate were identified for the other two sites and no detections were identified at any site during application (Jones et al. 2000b). The spring 2000 samples, from six locations, were collected either immediately after application or during the first rain-runoff event that occurred a few days post-application. Atrazine was not detected at any site. 2,4-D was detected at three sites in concentrations ranging from 0.10 to 0.58 ppb. Triclopyr was detected at the same three sites in concentrations ranging from 0.12 to 1.06 ppb (Wofford et al. 2001).

Overall, 31% of the 35 2,4-D samples had detectable concentrations and 27% of the 71 triclopyr samples had detectable concentrations. All detections were below the Board's operational standard of 10 ppb and were also below the California Department of Fish

and Game's estimated chronic toxicity threshold of 30 ppb for triclopyr (Jones et al. 2000b, Wofford et al. 2001).

North Coast Regional Water Quality Control Board -- California

The North Coast Regional Water Quality Control Board is one of several regional boards regulating water quality in California. This Board's jurisdiction includes largely forested lands west of the northern portion of California's Sacramento Valley and north of the San Francisco Bay Area. Timber harvest is a major commercial enterprise under this Board's jurisdiction. The Board has sponsored water quality monitoring by both state and timber industry staff.

Aerial spraying

Helicopter herbicide application in northwestern California has traditionally aimed at reducing competition in conifer plantations from noncommercial plants. In 1984 the Board published BMPs as "... the standard of performance for aerial application of herbicides on privately owned timberlands" (Wright-Shacklett 1998). Aerial application of herbicides on private timberlands within the jurisdiction of the North Coast Board declined from approximately 14,000 acres per year between 1984 and 1987 to approximately 1,200 acres in 1997. Wright-Shacklett (1997 and 1998) reported the following results of water quality sampling conducted primarily by private industry, but including some independent collections and analyses by Board staff, associated with aerial spraying of a variety of herbicides:

Sample Collector	Year	Herbicides	No. Samples Analyzed	% Samples < 2.01 ppb	% Samples < 10.01 ppb	% Samples > 10.01 ppb	Comments
Unspecified	1974-1983	Unspecified	895	91.1	97.9	2.1	--
Unspecified	1984-1996	Unspecified	1744	95.0	99.5	0.46	--
Unspecified	1974-1997	Unspecified	2668	92.9	98.9	1.1	--
Timber Industry	1996	Triclopyr (Garlon), 2,4-D, hexazinone	42	73.8	97.6	2.4	Detectable hexazinone in all 30 spring snowmelt samples
Timber Industry	1997	Unspecified	29	100	100	0	
Regional Board	1996	Triclopyr (Garlon), 2,4-D, hexazinone	18	77.8	94.4	5.6	4 hexazinone detects; 1 Garlon detection
Regional Board	1997	Triclopyr (Garlon) + unspecified	4	100	100	100	

In 1996 and 1997 samples were collected during spray operations and during the first storm event that produced runoff within 30 days of treatment. Scheduling of sample collection prior to 1996 is unknown.

Ground application

As aerial treatments declined, ground application of herbicides increased so that by 1997 approximately 15,000 acres were ground-sprayed in two northwestern California counties alone. In response to the increased ground applications, and to public concerns regarding ground treatments, Board staff sampled surface waters for atrazine and Garlon in 1997 either concurrent with application or during the first storm occurring within 30 days of treatment. No herbicides were detected in the 8 samples collected (at detection rates of 0.50 and 0.10 ppb for atrazine and Garlon respectively) (Wright-Schacklett 1998).

BMP issues

Prior to the 1997 ground sampling Wright-Schacklett (1997) stated: "When management practices are conducted in compliance with State regulations and herbicide labeling requirements, the threat of discharge of herbicides to waters of the State is far less from hand application compared to aerial application."

The Board report does not explicitly describe the rationale for this statement but did state:

> Small watercourses in older plantations [described elsewhere as "overgrown"] were not always visible from the air and vegetation covering them was occasionally sprayed. Little of the herbicide would get into the watercourses at the time of application but would show up during storm monitoring events when rain would wash the herbicide directly from the vegetation into the watercourses. These events are less likely to occur on young plantations where the watercourses and protecting vegetation are readily apparent from the air. (Wright-Schacklett 1997)

BMP effectiveness

In February 1998, Board staff stated "It had been demonstrated over the preceding 10 years that, when herbicides were applied by aircraft in accordance with BMPs, little or no discharge of herbicides waters occurred" (Wright-Shacklett 1998). Staff stated more specifically in 1997:

> It had been demonstrated over the preceding 10 years that, when herbicides were applied by aircraft in accordance with BMPs, discharges of herbicides to waters of the State seldom exceeded 10 parts per billion (ppb). ... the results indicate that proper implementation of BMPs has been successful in achieving water quality protection.

Oregon State Department of Forestry (Oregon DOF 1992)

In response to the following question from Oregon's Department of Forestry (DOF) Monitoring Program Plan, "Is water quality and public health being effectively protected

by the Forest Practices Program when forest management chemicals are applied?", DOF analyzed 52 composite water column samples collected in 1989 and 1990 in western Oregon from 50 herbicide application units.

Methods

Only herbicides applied near streams were sampled. Forty-three of the units sampled were on private forestland. The bulk of the remaining units were managed by DOF. Two units had ground applications; all other units were aerially treated. Buffers for the aerial units were at least 60' wide. Ground unit buffers were at least 10' wide. Twenty-six of the 50 units were treated with either glyphosate or 2,4-D, the others with atrazine, triclopyr, imazapyr, 2,4-DP, hexazinone or picloram, or combinations thereof. Detection limits were below one ppb (except atrazine—up to 4 ppb, imazapyr—5 ppb, and glyphosate—up to 2 ppb). Herbicide application rates are not given. Samples were collected ¼, 4, 8 and 24 hours after application to estimate 24-hr mean concentrations. These samples were composited. If the composite had an undetectable concentration no further analysis was undertaken. If detectable concentrations were found, the individual samples were analyzed to better quantify the 24-hr mean concentration. Over 80 individual and composite samples were analyzed.

Results

Eighty-three percent (43 composites) had no detectable concentrations. The other nine composites had detections ranging from 2.1 to 30 times less than surface water monitoring criteria developed by Oregon State University. Most of the detectable concentrations were from atrazine and triclopyr, with detections in seven of the 16 units using these chemicals. Estimated 24-hr concentrations ranged from 0.2 to 2.6 ppb for atrazine and <0.1 to 1.4 ppb for triclopyr. Maximum concentrations for these two herbicides were 7.52 and 2.5 ppb. Glyphosate and 2,4-D were each detected in single units with maximum and estimated 24-hr concentrations of 2.0/0.6 and 2.5/0.3 ppb respectively.

Herbicide detections did not appear to correlate with unit size, precipitation occurrence or wind speed. Five of the nine units with detections had unfavorable wind direction (towards the stream from the spray unit). All three of the triclopyr units sampled with a diesel carrier resulted in detections. Detections occurred only during March and April applications. Drift damage to vegetation was observed 30' into one 60' buffer. Most of the riparian overstory vegetation had been lost in this buffer to an escaped burn seven years earlier.

Discussion

Detections soon after application (15 min) would seem to have been caused by direct spray or drift; no other mechanisms could result in detection so quickly after application. However, the report authors state there was no observation of direct application of herbicides to Class I waters. Furthermore, "... the rules required leaving unsprayed strips

at least 60' in width along Class I water and other areas of open water." (ODF 1992:2). The "other areas of open water" would seem to imply that non-Class I open waters would be buffered. Nevertheless, it may be that Class II waters (those not having significant fishery, recreation or domestic use) were actually not buffered and direct spray onto Class II waters was the cause of the detections.

Conclusions

ODF (1992:16) concluded--

- "... none of the estimated 24-hr mean concentrations measured were at levels where they pose a risk to human health or aquatic life" and from these comparisons, concentrations of herbicides in forest streams should not pose environmental or human health hazards.
- "The most likely causes for herbicides to reach Class I waters are spray drift from the target areas and herbicides entering Class I waters from in-unit Class II waters."
- "Factors such as wind direction, type of carrier, time of year, and unit size can have an influence on the potential for spray drift. Early spring applications may involved a greater risk of herbicides reaching streams because vegetative cover is reduced and more water is present in and near the target area. Large units, which are more likely to contain small Class II streams or longer affected Class I stream perimeters may be more likely to produce measurable residue levels ... ."
- "Unsprayed strip widths of at least 60' appear to provide adequate stream protection during aerial applications when other conditions are favorable."

Ouachita National Forest – Arkansas

In the late 1980s and early 1990s herbicide application on the Ouachita National Forest had a variety of objectives, including understory removal to improve habitat for Red Cockaded Woodpeckers, eradication of poison ivy in campgrounds, and removal of undesirable vegetation competing with young trees (Clingenpeel 1993).

Between 1989 and 1993 stream water samples were collected at 168 sites on the Ouachita Forest adjacent to or within units treated by a variety of ground applications techniques (e.g., soil spot, cut surface, basal spray, hand foliar and mechanical foliar spray). The standard suite of BMPs used on the Ouachita Forest for herbicide application—including national Forest Service regulations augmented by local standards and guidelines—was implemented. An objective of the monitoring was "to determine if herbicides are present in water in high enough quantities to pose a threat to human health or aquatic organisms. This would indicate ineffective BMP's" (Clingenpeel 1993).

Methods

Up to three grab samples were collected at a site, one each after the first three post-treatment rainfalls of at least one-half inch. Two hundred sixteen samples were analyzed

for triclopyr (Garlon), 78 samples for glyphosate (Roundup), and 54 samples for hexazinone (Velpar). Detection limits were 0.0001 ppm for Garlon, 0.0005 ppm for Roundup and 0.001, 0.0015 or 0.002 ppm for Velpar. Samples were collected from all twelve ranger districts on the Ouachita Forest.

Chemical concentrations were compared against the following criteria to assess BMP effectiveness:

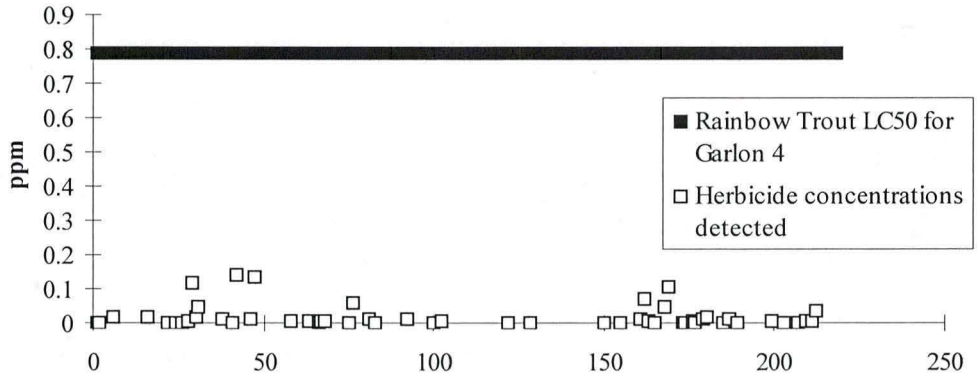
- Garlon
  - US EPA residue limit for milk: 0.010 ppm.
  - Temporary potable water residue limit: 0.5 ppm.
  - Garlon 3a fish toxicity: 100 ppm.
  - Garlon 4 rainbow trout and bluegill LC50s (respectively): 0.79 and 0.87 ppm.
- Roundup
  - US EPA potable water residue: 0.10 ppm.
  - "Levels toxic to fish": 2.0 ppm.
- Velpar
  - US EPA residue limit for milk: 0.10 ppm.
  - "Concentrations necessary to affect fisheries": above 100 ppm.

Results

Over 23% of Garlon samples had positive detections, as did over 10% of Roundup samples, and over 18% of the Velpar samples. Highest concentrations detected were 0.144 ppm for Garlon, 0.0068 ppm for Roundup, and 0.015 ppm for Velpar. Clingenpeel (1993) concluded that none of the concentrations detected would negatively affect fisheries. Percentages of positive detections, by herbicide, application method and purpose of application are given below:

	Garlon	**Roundup**	**Velpar**
Method			
Cut surface	24.1	4.3	0
Hand foliar	23.5	4.2	--
Mech. Foliar	22.2	19.4	--
Basal stem	13.3	--	--
Soil spot	--	--	19.6
Purpose			
Site prep.	22.4	0	20.8
Release	29.5	3	0
Row	16.7	19.4	--
Wildlife	0	--	--
Noxious plant	--	16.7	--

Garlon detections are plotted below relative to the rainbow trout criteria for Garlon 4.



Clingenpeel (1993) concluded that no single method or purpose resulted in higher occurrences of offsite Garlon detection. He did not comment on detections by method and purpose for Roundup and Velpar other than to note the higher percentages of detections for each chemical by method or purpose.

BMP effectiveness

In summary, Clingenpeel (1993) stated that BMPs "...used in the transportation, mixing, application and disposal are effective at protecting beneficial uses." He recommended continued herbicide monitoring of surface waters, emphasizing all methods and purpose of herbicide treatment.

Stanislaus National Forest -- California

Since the late 1980's with the publication of a regional vegetation management EIS, national forests in California have been directed "... to implement water monitoring to evaluate the effectiveness of project design for all projects involving herbicides" (USDA Forest Service 2003). Major wildfires on the Stanislaus Forest starting in 1987 instigated the largest reforestation effort to date in the Pacific Southwest Region (California and the Pacific Islands) of the USDA Forest Service.

As with many of the other case studies and examples in the literature, this monitoring was not explicitly directed to evaluating BMPs, rather the objectives of the monitoring were to—

- Determine if herbicide moves off-site and into water.
- If so, determine the amount of herbicide in water under differing flow conditions and the persistence of herbicide residue in water.
- Assess compliance with water quality objectives and guidelines (USDA Forest Service 2003b).

Effectively, however, recommendations from this monitoring program directly relate to BMP implementation and effectiveness.

Best Management Practices

Seven BMPs were applied. They mandate pesticide use planning, adherence to product label and other legal requirements, monitoring needs, disposal of pesticide containers and equipment, streamside and wet area protection during spraying, spill contingency planning, and pesticide drift control (see also Appendix F, California).

Methods

Hexazinone, glyphosate and triclopyr were applied (glyphosate and triclopyr by backpack sprayer and hexazinone both by ground and aerial methods) to over 21,000 acres on five reforestation projects between 1995 and 2000. Because of limited experience and knowledge of the fate of hexazinone in local watersheds both site (treatment unit)- and watershed-scale monitoring sites were incorporated into the monitoring design. BMPs implemented included those agreed to in 1981 by the Pacific Southwest Region of the USDA Forest Service and the California Water Resource Control Board (USDA Forest Service 2000).

Beneficial uses of water in the treatment area and downstream were domestic use, agriculture (irrigation and livestock watering) and freshwater habitat. Water quality criteria for these uses were quantified from US EPA Health Advisory information and toxicity research for aquatic freshwater species. The Health Advisory levels are more stringent than the aquatic biota criteria so the Advisory levels were identified as the numerical objectives. They were 200 ppb for hexazinone, and 700 ppb for glyphosate. No Health Advisory concentration was identified for triclopyr. The most stringent narrative objective—identified in the applicable Water quality Control Plan for the Central Valley Regional Water Quality Control Board--was to "not exceed the lowest levels technically and economically feasible" (USDA Forest Service 2003b). For hexazinone this level was expected to be between 100 and 200 ppb and non-detection for glyphosate and triclopyr.

A primary BMP was Streamside Wet Area Protection During Pesticide Spraying. Buffers were established 100' wide for hexazinone aerial spraying, between 10' and 100' for ground hexazinone application depending upon presence of live water and status as a main stem or tributary channel, and between 10' and 20' for glyphosate and triclopyr ground treatment. No rationale is given for these buffer widths (see however, interview comments by J. Frazier). Other specifics of the monitoring design and sample collection procedures are described in the Monitoring Procedures section of this report.

Results

Almost 1,200 samples were collected and analyzed over 5 years, with the bulk of these—890 surface water and 84 groundwater—assessed for hexazinone. Three of the 890 hexazinone samples from surface waters had concentrations were above the numerical water quality objective (with one at 600 ppb) and another nine samples had

concentrations above the 100 ppb level anticipated to be the "... lowest levels technically and economically feasible". Circumstances for these "elevated" concentrations are described below in the BMP Issues section. There were no detections from the 55 glyphosate samples collected and the highest triclopyr concentration detected was 5 ppb. Sampling results are summarized below as cumulative percent of all samples collected by herbicide and for hexazinone by watershed vs. site scale:

Detection Amount (ppb)	**Hexazinone**				**Triclopyr**	**Glyphosate**
	Surface water	Ground water	Watershed scale	Site scale	Surface water	Surface water
> 200	100			100		
101-200	99			99		
51-100	98			98		
11-50	96		100	95		
1-10	85	100	98	83	100	
< 1	58	87	71	55	87	
Non-detected	30	70	33	28	50	100

Downstream dilution commonly reduced site-scale hexazinone concentrations where surface water exited project boundaries and all hexazinone samples collected at the watershed scale met numerical and narrative criteria (USDA Forest Service 2003b).

Pre-project analysis had anticipated up to one year persistence of hexazinone. Monitored hexazinone persistence ranged from about two months to almost five years in surface waters. Groundwater well sampling also demonstrated hexazinone persistence to five years, although at "very low" concentrations, usually less than 1 ppb (USDA Forest Service 2003b). Hexazinone concentrations increased during storm flow versus baseflow periods (e.g., long periods between storms and summer low flows).

Triclopyr was not anticipated in pre-project analyses to be detectable in surface waters. Reasons for the low--but persistent for 6 months at some units--concentrations of triclopyr were unclear. Where detected, triclopyr was found in storm flow samples following application; concentrations tapered off to non-detections after several storms.

Glyphosate was not anticipated in pre-project analyses to be detectable in surface waters and monitoring did not identify glyphosate in detectable amounts.

BMP Issues

Reasons for elevated hexazinone concentrations offer insight on options to improve BMP implementation and potentially to revise BMPs.

The three hexazinone samples having concentrations above the numerical criteria were collected during one storm over a few hours at one location in 1996. A field review subsequent to the monitoring concluded that Pronone 10G was probably mis-applied, "...

evidentally on shallow soil/bedrock in and near a buffer where it subsequently washed off into the stream" (USDA Forest Service 2003b). It is unclear whether any BMP addressed this soil condition. If so, presumably the BMP was improperly implemented; if not, this condition potentially needs to be incorporated into future BMPs.

Hexazinone detections in surface waters in the mid-60 ppb range in two instances triggered field reviews in 1997. It appeared that helicopter flight heights were increased to avoid hazardous snag trees. The increased height potentially caused wider herbicide dispersal and hexazinone entry into the buffer zone (USDA Forest Service 2003b). In one instance the review teams determined that the map (delineating buffers) provided to the helicopter pilot immediately before flying showed many more buffers than the map originally provided to the pilot months before treatment. Apparently conditions had changed between contract development and herbicide application, due to unusually wet winter and spring weather. Other candidate factors contributing to the situation were—

- Possible safety issues associated with flying parallel to buffers in irregular terrain and problems seeing the orange panels delineating the buffer edges if not flying parallel to the buffers.
- The use of on-helicopter GPS for precise treatment near buffers.
- Adequacy of on-site management oversight to assure that corrections were made after herbicide was observed falling with buffers.

The review teams recommended—

- Changes in contract specifications.
- Re-evaluation of the use of 100' buffer strips to consider the location and aircraft height needed for safety flying to avoid obstacles.
- Site-specific modeling and reconnaissance for each application unit to map any terrain or obstacle that could alter flight patterns.
- Authorization of aerial hexazinone applications only after site-specific field review to determine the feasibility of aerial treatment.
- Initiation of methods for real-time assessment of buffer width adequacy.
- Staying on top of the potential need to initiate "changed conditions" contract actions.
- Requirements for new contractors to prove their ability to accurately apply chemicals along buffers.
- Pre-treatment surveys for live water in sufficient detail to assure no hidden water bodies receive direct application of herbicide.
- Prompt notification to the contractor of any need for corrective action, and ceasing treatment if immediate corrective action is not taken.
- Review of the suitability of GPS equipment for use in helicopter spraying.
- Provision of training of FS staff on the latest information on pesticide application technology and current legal requirements (USDA Forest Service 2003, Appendix F, Correspondence Related to Project Reviews).

USDA Forest Service Pacific Southwest Region Water Quality Monitoring Review

Bakke (2001) summarized herbicide water monitoring results for the Pacific Southwest Region (California) of the USDA Forest Service for the period 1991 to 2000. Some of the monitoring summarized in Bakke (2001) includes information presented above for the Stanislaus and Eldorado National Forests. In addition to information from those two forests, Bakke (2001) addressed monitoring conducted on two other forests in the Sierra Nevada/Southern Cascade Mountains, the Sierra and Lassen National Forests, and one small glyphosate monitoring project on the Angeles National Forest in the San Gabriel Mountains of Southern California.

Three herbicides were used during 1991-2000 on the forests: triclopyr, hexazinone and glyphosate. Glyphosate and triclopyr were applied exclusively by ground techniques; hexazinone was applied from both air and ground. Except for the noxious weed application on the Angeles Forest, reforestation was the primary purpose of the herbicide treatments. Between 1991 and 2000, about 113,000 acres were treated, in more than 30 separate projects.

Bakke (2001) summarized his findings as follows:

> Results ... indicate that glyphosate and triclopyr are rarely detected in surface water. This result is expected from the respective herbicide characteristics. Detections have been associated with use within riparian areas or not following established Best Management Practices. ... Hexazinone has been detected numerous times in both surface and ground water, which is also expected, based on the herbicide characteristics. If label direction and Best Management Practices are followed, detected amounts of hexazinone are very low. Projects utilizing hexazinone should be carefully designed to reduce the chances of unintentional direct introduction of hexazinone into surface water.

Bakke (2001) further concluded that when BMPs are properly implement, the monitoring results show that target surface water contamination levels (per a regional EIS) of 10 ppb per pound active ingredient are met. Most of the water samples had either undetectable herbicides or detections at very low concentrations.

The following herbicide-specific findings are taken directly from Bakke (2001):
Hexazinone:

- Once detected, the levels of hexazinone in groundwater are very low (max 2.1 ppb).
- Lag time and amount of positive detections with depth vary considerably. Once hexazinone is in shallow groundwater, lateral movement can be extensive (example, Peddler Hill springbox was about 450 feet downhill from treated unit).
- It appears from the surface water data that groundwater can continue to feed hexazinone into surface water over a long period of time, regardless of implementation of BMPs to directly protect surface water.
- It does appear that high subwatershed levels of hexazinone are quickly diluted downstream.

- It also appears that these small subwatersheds, if they have high levels of hexazinone detected in the first wet season, can have high pulses of hexazinone the following year.

Glyphosate:

- There were no detections in water or sediments in any samples taken after reforestation projects (that were not ascribed to sample contamination).
- The one type of project with a detection of glyphosate involved treatment of noxious weeds within the riparian zone. Even here, only one of twelve samples had a detection, and that was at a low level (15 ppb), below any level of concern for human health or aquatic resources.

Triclopyr:

- The few positive detections in non-accidental or erroneous applications in water monitoring are all at low levels (highest 2.4 ppb).
- The use of untreated buffers of some minimal size on ephemeral drainages (ten feet is the smallest implemented buffer involved in these projects) is needed to avoid levels of triclopyr in water that exceed the R5 FEIS expectations.
- The detection that resulted in the highest level of triclopyr (82 ppb) was the result of an absence of an untreated buffer on an ephemeral stream.
- It would appear from these monitoring data that untreated streamside buffers of greater than 15 feet in width reduce risk of water contamination to near zero, although it should be noted that the 82 ppb transient level does not represent a substantial risk of harm to humans or the environment.

Herbicide	Total Samples[1]	With No Detectable Residues	0-10 ppb[2]	11-30 ppb	31-50 ppb	51-100 ppb	101 - 600 ppb	Maximum observed concentration[3]
Glyphosate	104	103		1				< 25 ppb
Triclopyr	43	30	12			1		82 ppb
Hexazinone								
Surface	580	245	301	16	4	8	6	600 ppb
Ground	103	78	25					2.1 ppb

[1] No control or pretreatment samples have been included in this table.

[2] ppb = parts per billion

[3] Where limit of detection (LOD) may be higher than a reported concentration, the maximum has been listed as "less than" (<) the LOD. This is the case with glyphosate. The 600 ppb hexazinone sample is discussed above in the section on the Stanislaus National Forest.

NOAA Biological Opinions

Several Biological Opinions (BOs) were written in the last few years for noxious weed control, and other herbicide applications proposed by BLM and the FS in the northwest. The following text distills NOAA's commentary on BMP effectiveness from these Opinions.

The BOs acknowledge the general effectiveness of BMPs, including buffers, reduced herbicide application rates, ground application and other practices, with statements like—

- "...based on the proposed ground based applications the amount of chemical reaching the water through wind drift is likely to be minimal and below concentrations where lethal or sublethal effects are known to occur in salmon or steelhead" (NOAA 2003d)
- "Aquatic biota may be directly exposed to herbicides that are applied directly to stream channels; however, risks of contamination can be *reduced* if adequate no-spray buffers are maintained (Heady and Child 1994, cited in NOAA 2003a)
- "... it is expected that implementation of project BMPs as described above would minimize the risk that the included four herbicides and surfactants would reach downstream SR [spring/summer Chinook] salmon, and SR and MCR [Middle Columbia River] steelhead habitats in concentrations sufficient to elicit lethal effects." (NOAA 2003b)
- "[T]he risk [of exposure of aquatic biota to herbicides] is further reduced by use of hand application techniques (as as opposed to aerial application) ... " (NOAA 2003a).

The BOs definitely do not, however, presume complete effectiveness of BMPs by noting—

- BMP inadequacies identified in Rashin and Graber (1993) (NOAA 2002, 2003b and d)
- "toxic levels of chemicals may reach streams from storm runoff and wind drift even when best management practices are employed." (Spence et al. 1996, cited in NOAA 2003a)
- "Standard BMPs have been shown to be insufficient to completely eliminate drift and runoff, and modeling, despite their complexities, have not been sufficiently developed to be able to predict the risk of spray drift." (NOAA 2003a)
- "... there is some uncertainty about the effectiveness of the BMPs and the amount of chemical expected to reach the water. The scientific literature reviewed in the BA and this Opinion indicates that BMPs generally reduce the amount of herbicides reaching the water, but don't prevent it from getting in." (NOAA 2003b)
- "... the use of no-spray buffers and additional BMPs along stream courses is expected to minimize the amount of chemicals reaching the water. Nevertheless, given the uncertainties of BMP effectiveness and chemical fate and transport modeling predictions, listed fish could be harmed by exposure to herbicide concentrations that cause sub-lethal, or indirect environmental effects." (NOAA 2003b)

Industry Summary of Forest Chemical Mitigation Measures, and Limiting and Complicating Factors

The following summary is taken directly from NCASI (2000). This report lists several chemical mitigation practices in use by, or proposed for use by, the timber industry for

aerial herbicide application. Text for most of these describes the practice, measures of effectiveness, limiting and complicating factors, and complementary practices. As comments on the potential effectiveness of the practices, the summary below lists the limiting and complicating factors from NCASI (2000). A brief description of each practice is given parenthetically.

Chemical Drop Size Control Equipment Variables (nozzle type, size, orientation and application pressure)

Larger droplets are generally effective for soil-activated chemicals but can have limitations for contact chemicals like glyphosate.

Chemical Applications with Half-Booms (split-booms) near Streams (turn off boom on side of aircraft closest to water body to reduce drift)

The half-boom method is unlikely to produce many benefits where stream density is high and tributaries enter at right angles to streams in the treatment unit.

Weather Restrictions (wind speed, air temperature and relative humidity triggers for discontinuing spray application)

Extended period of fog restricts application, as do rain or excessive winds.

Application Procedures: Height of Application, Spraying Parallel to Buffer

Trees or other vegetation in spray units and buffers can cause aircraft application heights to be higher than desirable for environmental objectives due to safety considerations. Tributaries entering at right angles can effectively prohibit flight parallel to buffers and streams.

Swath Displacement (Aircraft operators monitor wind velocities and not the spray plum shift flight paths to compensate for wind)

Inversions and wind variation inhibit the effective use of swath displacement.

Buffers

Factors reducing the effectiveness of buffers include—

- Weather (erratic winds and inversions can increase drift).
- Heavy rainfall immediately following treatment may wash chemicals off plants and carry herbicides into runoff.
- Highly mobile and persistent herbicides in soil may leach through soils and enter surface waters by subsurface flow.
- Volatilization or wind erosion may cause re-suspension of herbicides and create additional chances for contamination.

- Rainfall or long-distance atmospheric deposition may carry low levels of herbicides.
- Intermittent or ephemeral streams that may be difficult to identify may provide direct herbicide transport to stream systems.

Vegetated Buffers (maintaining vegetation in buffers to intercept spray drift before it reaches water bodies)

Vegetation in the buffer can create atmospheric boundary conditions that induce spray drift droplets to carry past the buffer into the adjacent water body. If wash-off from the vegetation occurs from rainfall soon after application, peak herbicide concentrations in surface waters may be elevated. This process would not increase the total herbicide load reaching surface waters. The buffers would be less effective in the dormant season if the plants are deciduous.

Hand and Ground Application (Spotgun, stem injection, and other ground-based applications that minimize herbicide amounts and tightly control the location of herbicide entry into plants or soil)

Some leaching of herbicides has been documented even for stem-injected operations.

Other Studies

Four investigations are summarized below that are less comprehensive or relate less directly to herbicide application to forest and rangelands. These studies do, however, provide additional information on operational herbicide application in forest and rangelands, particularly for recent noxious weed control treatments in Idaho.

Oregon Roadside

To help identify the source(s) of the variety of herbicides detected in small Willamette Valley streams the Oregon Department of Transportation sponsored a two-year study tracking the disposition of several herbcides (Krovar (diuron and bromacil), Oust (sulfometuron-methyl) and Roundup (glyphosate)) in roadside ditches and a natural creek after simulated and natural rainfall (Wood 2001).

The herbicides were applied initially in spring 1999 to a road shoulder and monitored at the shoulder edge (with no buffer) after simulated rainfall. Rainfall was simulated (at 0.3"/hr) 1, 7 and 14 days after treatment. Results from the rainfall simulation suggested that concentrations of several hundred ppb of sulfometuron-methyl leave and nearly 1,000 ppb of glyphosate or diruon, could leave the road shoulder (bromacil was not applied in the simulated rain phase of the study).

At the end of September 1999 spraying was repeated on the road shoulder. Herbicide concentrations were monitored from the end of October through early January 2000

during natural rainfall at the shoulder, in a drainage ditch located at the edge of the shoulder and in a stream that crossed under the test site. No buffer was installed and herbicide-laden runoff from the road shoulder entered the ditch directly. Sulfometuron-methyl concentrations were in the 0.1 to 1 ppb range at the shoulder for the 3-month monitoring period, and decreased from 1 ppb in October and November to 0.3 ppb in January in the drainage ditch. Sulfometuron-methyl was never detected in the stream, presumably because dilution lowered concentrations to below detectable levels. Glyphosate was never detected in should, ditch or stream samples.

Wood (2001) concludes from the field measurements that sulfometuron-methyl can persist for at least three months in road shoulder runoff, although at decreasing concentrations through time. From theoretical calculations based on the field data, typical roadside herbicide treatment could conceivably generate 0.3-0.6 ppb sulfometuron-methyl concentrations in the study stream, although heavy rainfall (e.g., 0.3'/hr for about one hour) would be required one day after herbicide application—a highly unlikely occurrence (Wood 2001).

Nez Perce National Forest (Idaho), Water Column Monitoring

Pilot water column monitoring of herbicides used for yellow starthisle and spotted knapweed identified no detections of clopyralid, dicamba, 2,4-D or picloram during the first significant rainfall, approximately 40 days after the last day of treatment in early august 2002 on the Nez Perce National Forest in north central Idaho (Gerhardt et al. 2002). The herbicides were applied by single-nozzle backpack sprayers, or ATV/truck-mounted sprayers with direct application to the target weeds. Water was no closer than 200' away from the nearest treatment unit. No BMPs are mentioned in Gerhardt et al. (2002). Depth- and width-integrated grab samples were collected from four creeks. Picloram was detected during herbicide application in one sample at 0.03 ppb. Source of the picloram is uncertain but may be drift from aerial treatment on private or state lands. Gerhardt et al. (2002) note that the 0.03 ppb detection of picloram is at a level 9,600 times lower than the No Effect Level for cutthroat trout fry growth.

BLM Cottonwood Field Office (Idaho) 2002 Noxious Weed Treatments

See Implementation Monitoring section for a description of the context of the effectiveness monitoring.

Multiple post-treatment, visual observations of the condition of non-target riparian vegetation within designated buffers were made. No water quality monitoring was conducted (USDI BLM 2002).

"There was no evidence of non-target mortality or harm to riparian or upland vegetation due to movement of persistent herbicides [picloram/Tordon] through the soil." This

includes special status plants. No adverse erosion or sediment effects were identified from any herbicide treatments (USDI BLM 2002).

USDI BLM (2002) concludes that "[B]uffers and other standard criteria are more than adequate in providing a margin of safety to prevent this herbicide [picloram/Tordon] from reaching living waters."

The following comments and recommendations were made (USDI-BLM 2002):

- "Continue constant and early coordination between specialists to assure new and existing projects are adequately addressed for clearance work, consultation, monitoring needs, marking sensitive plant species, etc.
- Identify specific streams or areas that Biologists would like to be present at during treatment or for post-treatment evaluation.
- It is recommended that an Ecologist or Zone Botanist be on site for all aerial or ground based herbicide application spray projects that are adjacent to or in close proximity to any listed or special status plant populations.
- When spray projects are adjacent to or in close proximity to any listed or special status plant populations, the boundaries of these plant populations should be flagged with Limeglo flagging. This is the standard flagging protocol that will be used on all BLM herbicide application projects.
- When herbicides are to be applied aerially adjacent to or in close proximity to any listed or special status plant populations, spray cards should be placed at the outer edge of the listed or special status plant population and at the edge of the protective buffer closest to the area to be sprayed. In addition, the edge of the spray buffer should be flagged with Pinkglo flagging which is easily observable from the aircraft which is to apply the herbicides. This is the standard flagging protocol that will be used on all BLM herbicide application projects.
- Wind speed and direction should be monitored hourly (more often if obvious changes in wind speed or wind direction are occurring), and if the wind speed exceeds the maximum allowed (5 mph) or if the wind direction makes it likely that drift will occur toward the listed or special status plant populations, then aerial herbicide application will be suspended (if in progress) or will not start.
- When possible, for aerial herbicide applications, a drift control agent such as Stay-Putt will be used to lessen the potential for herbicides to drift onto non-target vegetation.
- Post treatment monitoring should be done to assess effectiveness of spray buffers. If there are any observable effects to special status plants, spray buffers will be increased to minimize any chance for future herbicide effects to special status plants."

TexIS – Texas Intensive Silviculture Study

A forest industry study of the effectiveness of silvicultural BMPs is underway (TexIS 2003). This project addresses a suite of BMPs including herbicide practices. The field location is an east Texas upper coastal plain site dominated by loblolly pine. The first aerial herbicide treatment, in late September 2002, followed harvest in April through

June. Further specifics of this study are not known, other than that initial water column sampling for glyphosate (Accord), hexazinone/sulfometuron-methyl (Oustar) and imazapyr (Arsenal) detected low chemical concentrations in composite samples. As of mid-August 2003, the individual samples comprising the composites had not been analyzed (Shepard 2003).

Discussion and Interpretation

Perceptions on the effectiveness of herbicide BMPs range from uncertainty to belief in the general effectiveness of practices. Two factors influence these perceptions: applicable water quality criteria, and availability of documentation on herbicide levels in surface waters.

Protection of water quality is related directly to the operational definition(s) of water quality objectives, criteria or standards that can vary by state, sub-region or locality. Opinions on BMP effectiveness can therefore vary in adjacent localities if neighboring standards vary. BMPs are not perceived to be effective where "zero detection" standards are in place because monitoring data routinely show some detections of most herbicides in surface waters.

For the more common biological/beneficial use-based narrative standards, that are translated into herbicide concentrations based on toxicological studies, most workers acknowledge that monitoring data usually document herbicide concentrations considerably below triggering levels. Consequently BMPs are generally regarded as effective, and inadequate implementation is seen as the cause of any water quality problems. Unfortunately, effectiveness monitoring is uneven geographically and institutionally. The California region of the USDA FS has monitored concentrations of several herbicides extensively over the last 10 years. Hundreds of water quality samples have been collected and analyzed. Similarly extensive monitoring was not identified elsewhere by any agency. Unfortunately, the Forest Service results in California address only three herbicides, and because herbicide fate and transport is largely site- and herbicide-specific extrapolation of the California results to other locations is not apparent. Without site-specific monitoring the effectiveness of BMPs is unknown.

An issue allied to assessment of BMP effectiveness is the distinction between implementation and effectiveness. For instance, some workers believe that if a BMP prohibition on applying herbicides to live water is not adhered to, the BMP is not effective. Others would counter that the practice was not implemented properly.

Systematic research on the effectiveness of specific BMPs is minimal. By far the more common approach, both in "fate and transport" studies and operational monitoring by land management agencies, is quantification of water column chemistry to determine if applicable water quality criteria are violated. If herbicide concentrations are detected above the triggering criteria level or standard, a retrospective assessment of what went

wrong may identify BMP shortcomings. Otherwise the implicit presumption is that BMPs are effective.

The literature review, interviews and questionnaire responses identified several situations relating to effective protection of water quality. The two most common detections of herbicides in surface waters of forest and rangelands are concurrent with or immediately after (1) herbicide application and (2) the first or the first few rain-induced runoff events after application. These two situations for herbicide detection illustrate potential failings in BMP implementation. Herbicide detection in surface water concurrent with, or soon after application, is due to direct over-spray onto live water, or off-target drift; no other mechanisms can move herbicide quickly enough to be observed in water at the time of application. Prohibition on herbicide deposition directly onto surface water is a common forest practice rule, label directive or water quality standard, and BMPs directed at prohibiting deposition onto live water are common.

Two factors are cited as contributing to live-water deposition. First, identification of surface water is problematic where vegetation canopies are dense, particularly when surface water identification is from aircraft reconnaissance rather than walking a stream channel. Known surface waters are typically buffered, which reduces the likelihood of direct deposition onto surface waters. If live water isn't identified, it isn't buffered and overspray is likely. A related problem is change in the geographical location of surface water between its initial mapping and herbicide treatment. Mapping in the autumn, during relatively dry conditions may minimize the extent of surface water compared to spring when winter rains and snowfall expand the surface area of water bodies. Buffers mapped under dry conditions may be too narrow at the time of herbicide application. This is accentuated if timber harvest occurs between mapping and treatment. Tree removal will reduce evapotranspiration and consequent increase stream flow.

Second, with aerial application of liquid herbicide, the common practice of "swath displacement" attempts to account for wind-induced shifting of the cloud of herbicide spray droplets. Imprecise swath displacement can result in drift of spray droplets onto surface water.

Elevated herbicide concentrations associated with post-treatment rain storms result when ephemeral or intermittent stream channels that were dry at the time of application (and therefore were not buffered) channel herbicide-laden runoff to perennial streams. Buffering intermittent and ephemeral channels is a fix to this problem, although doing so could put appreciable acreages of land off limits to herbicide application, particularly in watersheds with high drainage densities.

Other situations that influence BMP implementation and effectiveness by elevating herbicide concentrations in surface waters are—

- Geologic conditions favoring rapid sub-surface water/herbicide flow to surface waters. Macropores or extensive near-surface bedrock or impermeable layers foster the rapid flows. Mapping and knowledge of groundwater dynamics and

geologic conditions could be better incorporated into BMPs to address this potentiality.

- Obstacles (e.g., snags or localized topographic high points) in the treatment zone near buffers that cause aircraft to fly higher than appropriate for minimizing draft. Better mapping of topography and vegetation near buffer boundaries could be incorporated into BMPs to address this potentiality.
- Watersheds with tributaries entering mainstem channels at right angles, particularly where drainage density is already high. This scenario causes problems because flightpaths in aerial application should parallel buffer and stream boundaries, otherwise the risk is great that drift or direct overspray onto surface water will occur. With high drainage density and right-angle tributaries, room will often be insufficient to fly parallel to the buffers. For these types of situations, ground application may be the best approach to assure water quality protection.
- Herbicide application in riparian areas for noxious weed control. This type of high-risk treatment can negate much of the benefit derived from riparian buffers for reducing surface water impacts.
- The use of aerial versus ground application techniques. Risks of impacts to water quality are much greater for aerial treatments.

As suggested above, many of these situations could be addressed by additional specificity in BMP documentation. For instance, rather than saying simply to assure no herbicide directly reaches surface waters, alternative BMP text could include examples where live water was not identified—presumably due primarily to invisibility from aerial reconnaissance flights—along with either a directive or strong recommendation to use all available means to identify live water, including aerial photos, maps, and above all walking the channels immediately prior to herbicide application.

Nevertheless, after all is said, observations of the "bleeding" of some herbicides into surface waters for months and years after application suggest that complete guarantees of zero detection may never be possible. Where zero detection is the standard, BMPs would presumably not be effective.

INFORMATION AND KNOWLEDGE NEEDS

Information needs expressed in the interviews and questionnaire responses are listed below.

Interviews

Research needs/information gaps include the need to field verify AgDrift, and assessment of the need to protect ephemeral streams. If further protection is needed, what is the best approach(es) (J. Shepard, National Council for Air and Stream Improvement)?

Sub-lethal effects on aquatic species are incompletely known. This ignorance prompts conservatism in buffer width designations (P. Grinde, FS).

Data and/or models for combined herbicide runoff and drift through buffers (E. Snyder-Conn, FWS Refuges).

Spray drift is the current primary focus for buffer width determination; more attention is needed to runoff and leaching/groundwater pathways of herbicide entry into surface waters (e.g., what are suitable buffer widths for non-drift routes of transport?). Better understanding is also needed on potential effects to fish. Before spending money and staff time attempting to determine buffer widths, we really need to better understand chemical effects on aquatic biota. The collective uncertainties about buffer widths and herbicide effects may drive decisions to avoid the use of herbicides rather than minimize their use (T. Buerger, FWS).

A better understanding and/or modeling capacity for herbicide runoff through buffers is needed (P. Durkin, Syracuse Environmental Research Associates).

Questionnaires

BMP Implementation

No information needs listed in the questionnaire responses except for a question on the need for formalized herbicide BMP implementation monitoring in the Pacific Southwest Region of the USDA Forest Service.

BMP Effectiveness

Rather than BMP effectiveness, the knowledge gaps are in how much of a risk these herbicides pose to aquatic resources at minute levels that may even reach live waters given label requirements let alone standard BMP implementation. The information used by NOAA fisheries to raise the "red flag" was data about DDT, an insecticide which was banned for a mirad of reasons. And some information on Atrazine, a herbicide which may be used by BLM but is not one of the main herbicide tools. We are working with

expanded buffers, without knowing that there is even a risk for the most common herbicide tools. (Danly)

We are looking to further test half booms, drift control adjuvants, foliage interception, and complex terrain effects. Runoff from storm events is also an important issue that we want to address. (Ice)

Adjuvant toxicities. (Lind)

Discussion and Interpretation

The interviewees and questionnaire respondents did not identify many information needs. The questionnaire clearly asked for information needs, but this topic may have been missed in some of the interviews.

Limiting information needs strictly to BMP-related items, reduces the list further, although topics like adjuvant toxicity and biological effects of herbicides do relate to BMPs in that unknowns about biological effects tend to foster conservative approaches to decisions on buffer widths and related BMPs.

A comprehensive search for information needs was not undertaken during the literature review. Several information needs expressed in the literature parallel those identified by the interviewees or questionnaire respondents. Rashin and Graber (1993) cited the need to—

- Evaluate the feasibility of alternate spray nozzles and boom systems, to allow better control of drift and to expand options for using a broader range of droplet size spectra.
- Develop more effective procedures for identifying live water.

USDC NOAA (2003d) cited the general lack of information on herbicide fate and transport in forest ecosystems, as well as the incompleteness of information on ecological effects of herbicides. NCASI (2000) noted the limited information available on the effectiveness of vegetation for intercepting fine spray droplets.

From the limited information on knowledge and information needs, it's hard to generalize. Nevertheless, several topical areas stand out as herbicide BMP information gaps:

- Comprehensive, validated models addressing the full suite of pathways for chemical movement into water bodies (e.g., drift, runoff, sub-surface flow).
- Sub-lethal and other biological effects of herbicides, especially as they influence buffer width determinations.
- Potential improvements in herbicide application equipment and technologies (e.g., the efficacy of half-booms) that could provide better control for aerial treatments.
- Improved methods for systematically determining effective buffer widths.

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Appendix A. Summary Of Comments from Phone Interviews and E'mails

Tim Adams, Division Director, South Carolina Forestry Commission, Columbia, South Carolina, 803-896-8802. August 15 phone conversation.

- In early 90's in the South harvest was the focus, very little work on site preparation.
- Statistics from compliance monitoring results can be misleading, especially when the monitoring isn't designed for site prep activities but site prep (e.g., herbicides) is included anyway.
- Results of S Carolina compliance surveys
    - To the extent that problems existed, they were primarily associated with prescribed burning, often combined with herbicides.
    - For site prep application of herbicides overflights into buffers occurred.

Brian Amme, Project Manager, BLM Nevada, 775-861-6645. August 18 phone discussion.

- No information available.

Robert Anderson, IPM Specialist, NOAA, Portland, 503-231-2226. September 24 phone discussion.

- After receiving and reading questionnaire, and getting comments from colleagues on it, he felt he and his colleagues were not suited to respond. The questionnaire is addressed to action agencies.
- Effectiveness
    - Uncertain if BMPs work because NOAA isn't getting monitoring reports it asks for.
- Monitoring
    - Seen as critical tool to assess effectiveness. BMPs may be well designed, but without on-the-ground monitoring effectiveness of practices are unknown (e.g., did buffer work under condition X, Y, Z?)
    - In recent consultations NOAA has pushed fairly hard to get monitoring reports; hopefully they will be forthcoming in the future.
    - Much resistance from BLM, FS, and even FWS, to produce good monitoring results, especially with water quality monitoring (vs. drift cards). Contentious discussions with BLM in particular.
    - Without monitoring results/actual observations or measurements, there are uncertainties about how best to monitor.
- Buffer width
    - Many variables need to be considered (e.g., herbicide fate, application rate, type of application, geomorphology, distance of treatment from water,)
    - Although action agency states it will follow product labels, labels are not necessarily believable (by NOAA) because EPA typically isn't consulted.
    - Surfactants/adjuvants typically aren't clearly incorporated into label direction re buffer width; this is another uncertainty and cause for pushing for conservative buffers
    - Potential, but largely unknown, sub-lethal effects on aquatic biota are another impetus for conservative width decisions. For instance, LC50 data on daphnia may have little relevance to cold-water fish, and relying on daphnia LC50 information isn't particularly convincing (apples and oranges).
    - There is enough soft information available suggesting that some level of herbicide will reach water bodies, with BMPs implemented. Without multi-

tiered monitoring of soils and water, and without more systematic procedures for width determination, uncertainty is high re actual fate (concentration, persistence, intensity) of chemicals in water.
    - Can't always believe widths on labels, or there are alternative methods of determining widths that may give different widths (more uncertainty implying biologically conservative decisions).

Robert Auldes, Natural Resources Program Administrator, Washington Department of Natural Resources, Land Management Division, 360-902-1346. July 17 phone discussion.

- In the past (last 1980's/early 1990's) the State of Washington sampled streams on State lands for herbicide concentrations. Routine sampling has not continued because of cost and logistical difficulties with the need for timely sampling.
- BMPs are still implemented with the belief that little herbicide reaches streams.
    - Buffers are wider than required
- Recommended contacting Geoffrey McNaughton

Sam Austin, Hydrologist, Virginia Department of Forestry, 434 -977-6555. July 15 phone discussion.

- Herbicides are not an issue; sediment is.
- Virginia state field audits for implementation and effectiveness typically do not address herbicides.
- General utility of buffer zones recognized; major program underway to increase buffers around Chesapeake Bay.

Jim Bergman, Hydrologist, FS, NV, 775-355-5339. August 27 phone conversation.

- Not aware of implementation or effectiveness monitoring of herbicides on Humboldt-Toiyabe Nat'l Forest.
- The H-T only applies herbicides adjacent to roads.

Clay Brandow, California Department of Forestry and Fire Protection (CDF), Sacramento, 916-653-0719. July 7 phone discussion.

- CDF does not oversee herbicide BMPs; the California Department of Pesticide Regulation has this responsibility. Suggested contacts.

Ted Buerger, Environmental Contaminants Biologist, FWS, Portland, 503-231-6179. September 2 phone discussion and followup September 10 e'mail.

- Buffers
    - Uncertain how BLM/FS determine buffer widths.
    - Problems extrapolating AgDrift results to forested situations due to slope and forest vegetation, but model results may be best information available.
    - Until something better comes along use current width estimates with an added safety factor—but then determined the safety factor is problematic.
    - In Vale District BLM consultation used crude risk analysis based on chemical-specific toxicity to biota (bull trout) as basis for width determination; add X' to width if moderate concern, 2X' if greater concern. So species toxicity to specific chemical drives width determination.
    - In e'mail stated "... we adjusted the aerial buffer zones based on our level of concern for particular active ingredients."
- Monitoring information needs

    - Until we get better understanding of what active ingredients are doing to fish, before devoting significant money and staff time attempting to determine buffer widths, need to really know what chemical data (e.g., water column sampling) means re biota before detailed monitoring.
- Information needs
    - Understanding of behavioral effects of low concentrations of organophosphate insecticides needs to be improved. Concerns that low concentrations have dramatic effects that may drive regulatory agencies to avoidance (rather than minimization) of use of chemicals. If buffers will be required, need to be sure they can be implemented and will prevent low chemical concentrations in the water column. Important to know up front target concentration to be avoided.
    - Runoff and groundwater pathways of exposure need attention; what are suitable buffer widths for non-drift routes of transport?

Dave Burch, State Weed Coordinator, Montana Department of Agriculture, 406-444-3140. October 23 phone discussion.

- Background primarily agriculture and exotic plants (e.g., knapweed)
- BMPs are effective in protecting water quality if implemented properly (need explicit treatment plan and need to account for environmental concerns)
    - In grants program, treatment proposals are comprehensively evaluated at technical level re soils, groundwater, type of herbicide(s), etc. If proposal is inappropriate, it won't be accepted.
- Buffer widths are determined, often with models, by considering soil composition, slope, groundwater depth, herbicide, etc.
- Buffer effectiveness is monitored, typically on 25 projects/yr, by looking for effects on non-target vegetation. No water column sampling is done, although some groundwater testing may occur. Good communication with grantees (applicators) and comprehensive review of project reports also get at effectiveness.

Dr. Parshall Bush, Director, Pesticide Residue Analysis Laboratory, University of Georgia, 706-542-9023. July 24 and September 3 phone discussions.

- No technical comments re BMPs per se.
- Agreed to look at questionnaire.
- Detectability of forestry herbicides
    - Extremely low detectability levels (e.g., part per trillion or part per quadrillion costing upwards to $5,000/sample) are seldom reproducible by independent means (e.g., a second method of analysis).
    - One ppb can be independently reproduced.
    - US EPA asks for a second method of analysis to confirm positive detections.
    - Most forestry herbicides would likely be undetectable in surface waters under operational (1 ppb) detection limits after the first post-application storms.

Pete Caffereta, California Department of Forestry and Fire Protection (CDF), Sacramento, 916-653-9455. July 7 phone discussion.

- Confirmed Brandow's comments re jurisdiction of CDF. Suggested contacts.

Dr. Jim Cathcart, Acting Monitoring Unit Manager - Forest Practices, Oregon Department of Forestry, 503-945-7493. August 18 phone discussion.

- E'mail referencing effectiveness monitoring study and list of other technical documents (including 2002 compliance monitoring report)

- Confirmed that internet documents are the most recent available for Oregon State implementation and effectiveness monitoring.
- Referred question on relevancy of bio-assessment as effectiveness monitoring tool to staff assistant, Jim Paul

Jim Colla, Forest Practices Act Program Manager, Idaho Department of Lands, 208-769-1525. July 21 phone discussion.

- In 2001 a 70,000-acre project sprayed insecticide for tussock moth; no herbicide information.
- No further follow-up or discussion, because Colla has no information on herbicides.

Lynn Danly, BLM, Idaho, 208-962-3797. July 29 phone discussion.

- No technical comments during phone call.
- Agreed to complete questionnaire.

Jay Davis, Environmental Toxicologist, FWS, Washington, 360-753-9568. July 10 phone discussion.

- No technical comments; little experience/information re BMP implementation/effectiveness
- Recommended other contacts

Jerry DeGraff, Geologist, FS, California, 559-297-0706 ext. 4932. August 15 phone discussion.

- Focus is sub-surface/ground water monitoring for herbicide applications in central/southern Sierra Nevada.
- Decision process for application of hexazinone
    - Goal is to keep hex out of wells
    - Reviews location of existing wells with respect to proposed treatment location. Excludes hexazinone if direct subsurface pathways appear feasible to transmit the chemical. If no evidence precluding transmission (e.g., large canyon, or great distance, between proposed treatment site and well), hexazinone not excluded for groundwater reasons.

Dr. Michael Dosskey, Research Riparian Ecologist, National Agroforestry Center, Lincoln, Nebraska, 402-437-5178, ext. 25. October 21 phone conversation.

- Research on the effects of buffers on pesticides is much less than similar research on sediment and nutrients, primarily because sediment and nutrients cause more widespread problems and pesticide research is relatively expensive.
- Nevertheless, to the extent that pesticides can be grouped into those that bind to sediments and those that dissolve, research on sediment and water flow through buffers is relevant.

Dr. Patrick Durkin, Environmental Toxicologist, Syracuse Environmental Research Associates, Syracuse, NY, 315-637-9560. August 15 phone conversation.

- Buffer issues
    - Drift and direct spray are crudely quantifiable (e.g., can be modeled)
        - AgDrift is as good a tool as any available. It allows specification of a variety of relevant physical and engineering parameters (e.g., wind speed, particle size distribution, nozzle size/orientation, air temperature, differing vegetation)

        - AgDrift not good for ground application.
    - Information need: More information/modeling capability for herbicide runoff through buffers. He's not aware of any off the shelf model that he's comfortable w/ for factoring in buffer in any site-specific way.
        - Field determination of buffer effectiveness is difficult because of myriad of site-specific factors and consequent variability (e.g., 100' buffer w/ modest clay depression running through it to channel won't be very effective, but a 10' loam buffer with no depression may be effective.

Scott Ferguson, Chief, Northern Watersheds Unit, California Regional Water Quality Control Board, Lahontan Region, 530-542-5432. September 4 phone discussion.

- No technical comments.
- Willing to route questionnaire to appropriate staff.

Laurie Fisher, Non-point Source Program Coordinator, Colorado Department of Health and Environment, Water Quality Control Division, 303-692-3570. July 17 phone discussion.

- Colorado state NPS program does nothing re herbicide BMPs.
- Contact Phil Schwolert in Colorado Department of Forestry.

Michelle Frank, Regional Pesticide Coordinator, USDA Forest Service, Northeast Region, Newtown Square, PA, 610-557-4113. September 24 phone discussion.

- The NE Region of the FS is just getting back into using herbicides. There have been numerous gypsy moth insecticide applications though.
- Two forests currently have active herbicide programs, Alleghangy and Mark Twain. They may also have monitoring results.
- Frank will look for monitoring results and send any she finds, along with EISs
    - Nothing received as of 10/28/03.

Jim Frazier, Forest Hydrologist, Stanislaus National Forest, 209-532-3671 x 205. August 25 phone discussion.

- Buffer width determination
    - For aerial application: a written authority states width must be at least 100'
    - For ground application: professional judgment, plus early tests with backpack equipment, and trial/error experience.
    - Trade-off: To optimize reforestation, vegetation not affected by herbicide is removed manually. Manual removal, with a wider buffer, is sometimes not worth the trouble. Incentive is to narrow the buffer while still meeting water quality criteria.
- How determine if buffers properly installed/implemented?
    - By visual inspection after treatment of dead vs. live vegetation.
    - Also rely on contract inspectors and silviculturalists as part of team evaluating buffer effectiveness. They observe as project is ongoing and then come back after project finished.
    - Inspection during application is critical.
    - Nevertheless, there is no formally prescribed methodology for post-treatment inspection.
- How identify location of live water?
    - Office planning process initially identifies theoretical location of all waterbodies.
    - Field inspection/delineation of live water in autumn before spring application and again immediately prior to treatment to validate autumn waterbody mapping and

look for "new" waterbodies. Autumn inspection flags intermittent channels that could be live in spring.

- BMP implementation difficulties re live water
  - Scale: If concentration of small waterbodies (e.g., springs) in spray unit their relatively close proximity could hinder effective aerial spraying.
    - Solution: delete entire unit.
  - Snags: In reforestation applications snags can cause pilot to fly higher than mandated causing drift to spread further than anticipated.
- Sampling strategy
  - Strategy incorporated site and watershed scales and was conditioned on ignorance environmental fate of hexazinone. Wanted "worse case" (site scale) information. Project planning used PRIMS modeling which was also multi-scale. Strategy was designed partly to test PRISM model.
  - From results thusfar aerially-applied hexazinone in water will be well within water quality standards at both the site and watershed scale, so in future would sample at watershed scale only for hexazinone, glyphosate and triclopyr.
  - Scale of sampling should be geared to beneficial use of water. With no site-specific T&E species this equated to 6th field HUC; no need for smaller scale.
  - Timing of sample collection re stormflows depends on the properties of the herbicide.
  - Decision on nested sampling also contingent upon geomorphology (e.g., headwaters/dendritic channel morphology would lower need for site-specific sampling)
- Bio-assessment
  - Monitoring approach is determined partially in consultation with Regional Water Quality Control Board (regulatory agency). The Board has never pushed effects on in-stream fauna so bio-assessment has not been discussed as a monitoring option.
  - Wouldn't necessarily be cheaper.
  - In other operational bio-assessment projects, there is a significant delay in sample processing time, so presumably for herbicide effectiveness monitoring results would not be available on anywhere close to a real time basis.

Jim Garner, Virginia State Forester, 434-977-6555. July 15 phone discussion.

- Expressed concern/dismay re issue. Labels are explicit. If follow label instructions there will be no water quality impact.

Brett Glover, Ranger Conservationist Technician, FS, Humboldt-Toiyabe National Forest, Nevada, 775-778-0253. Early September phone message and e'mail exchange.

- Sent "Surface and Ground Water Quality Monitoring Protocol for Herbicide Application. No monitoring data available from the Forest.

Kathy Goforth, US EPA, California, 415-972-3521. August 15 phone discussion.

- No experience with BMPs.
- Offered information on contacts for topics related to BMPs, e.g., effectiveness of integrated pest management (as alternative to BMPs), and monitoring of aquatic herbicides.

John Greis, Environmental Specialist, FS, Florida, 850-309-0764. August 11 phone discussion.

- Implementation

    - There isn't a lot of good information at the state level.
    - Basic difficulty in visiting site long after treatment; don't know what was done/wasn't done on the ground.
    - Most southern states use yes/no questions for each BMP.
- Effectiveness
    - Information sources: Jerry Michael, Jeff Vowell, Southern Forests Resources Assessment … .
- Buffers
    - Not aware of any issues in South.

Peter Grinde, Project Manager, Payette Nat'l Forest, Idaho, 208-347-0338. August 12 phone discussion.

- Application
    - Treatment of noxious weed infestations scattered in small areas.
        - E.g., 100 actual acres scattered within 2400 acres treated in 2002.
    - Truck-mounted with hand gun, sometimes backpack with hand guns; never aerial.
- Implementation monitoring
    - Minimal, subjective, cursory. Ocular assessment of effect on target species and secondarily to non-target vegetation.
- Effectiveness monitoring
    - Minimal; no examples given.
- Buffer width determination
    - Process is via consultation with NOAA/FWS using product label information coupled with conservative assumptions.
    - One size fits all approach; although some sites could require 300' buffer and others 100', approach has been to standardize buffer width.
        - Would prefer customized, functional approach per product label (e.g., don't use product where water table is high or there is potential to wash into water)
- Scale of treatment
    - Concern that on scale of entire Columbia basin FS application is probably trivial compared to private land application.
- Information need
    - Need better information on sub-lethal chemical effects to aquatic biota. Buffer width determination problematic until better understand potential impacts to biota.

Moreland Gueth, Watershed Protection Forester, North Carolina Division of Forest Resources, 919-733-2162, ext. 255. July 29 phone discussion.

- BMP compliance surveys have traditionally focused on active harvesting, site prep activities like herbicide treatment are not segregated from a broad "site prep" category. Therefore no information on herbicide BMP compliance.

Jack Holcomb, Regional Hydrologist, Southern Region, USDA Forest Service, Atlanta, 404-347-5058. August 11 phone discussion.

- No information to provide. Suggested other contacts.

George Ice, Principal Scientist, National Council for Air and Stream Improvement, Inc., Oregon, 541-752-8801. July 24 phone discussion.

- No technical comments.
- Suggested others to contact.
- Sent publications on buffer modeling.

Craig Johnson, Fisheries Biologist, BLM, Idaho, 208-962-3256. July 24 phone conversation.

- Monitoring
  - In transition now, attempting to do more comprehensive monitoring
  - Little effectiveness monitoring; focus is on implementation
- Buffers
  - Width determination via informal risk assessment using GLEAMS modeling for fate/transport, and knowledge of toxicity to target species.
- Sent BA (identifying monitoring requirements) and other relevant documentation.

Steve Koehn, Maryland State Forester and Chair of National Association of State Foresters Water Committee, 410-260-8501. Phone message exchanges in mid-August.

- Expressed concern/dismay re issue. Labels are explicit. If follow label instructions there will be no water quality impact.

Andy Kulla, Lolo National Forest, 406-329-3962. Phone message exchange mid-July.

- Has audit/compliance reports for aerial application. Will e'mail.

James Liebman, US EPA, San Francisco, 415-947-4241. August 15 phone discussion.

- Not well versed in specifics for forest applications; he does crops
- Sent contact information for several individuals, and information on NPDES court suit re aerial application.

Leonard Lake, Nez Perce National Forest, 208-983-1950, ext. 4183. September 2 phone conversation.

- Has some monitoring data; will e'mail.
- Buffer width determination
  - Consider chemical fate, transport and toxicity properties, soil texture, and other site characteristics
  - FS gives contractor guidelines and defers to contractor for width determination. Guidelines include minimum width for any application.
- Needs options for water column monitoring procedures; sent him Oregon protocol

Richard Lee, Integrated Pest Management Specialist, BLM Denver, 303-236-1734. August 18 phone discussion.

- Advocates historical perspective; should compare water quality condition with current BMPs against condition with no BMPs—significant improvement.
  - Some herbicides used years ago are no longer registered by US EPA and are not used.
  - Herbicides are often applied at lower rates than in the past.
  - Don't underestimate progress.

Tom McClure, Regional Pesticide Coordinator, Rocky Mountain Region, USDA Forest Service, 303-275-5100. July 17 phone conversation.

- Most Rocky Mtn Region applications are away from water.
- Effects on target plant, water quality or drift are monitored. Noxious weeds is the problem.

- Water quality is not an issue re herbs in Region 2.
- Gave names of contacts.

Ed Monnig, District Ranger, Kootenai National Forest, MT (previously was toxicologist with FS), 406-882-4451. September 24 phone discussion.

- Noxious weeds are big issue in dry landscape of FS Region 1. Holding action; expect weeds to overwhelm landscape in future. Hope that biological approach will ultimately be a successful tool for weed eradication. In meantime, herbicides can be fairly effective at keeping new invader weeds at bay.
- Appreciable public phobia and misconceptions about effects of herbicide. For instance, inappropriate extrapolation of Tordon toxicity for some plants to toxicity to aquatic biota and humans. Also herbicide warnings often based on irrigation scenario, not forestry.
- Buffers and short-lived herbicides are required.
- Buffer widths
    - Width determination is not well founded in science. Hard to come up with scientifically-based rationale for specific widths.
    - 1 size fits all is a problem. Often width decisions are based on worse case scenario (e.g., irrigation water protection, not forestry). And application rate and areal extent are not considered (e.g., widths are the same for a few acres of noxious weeds with low application rate as ag field application).
- BMP adequacy
    - Depends on the chemical.
    - Would be great to have more site-specific buffer prescriptions, but current status of the science is inadequate.

Geoffrey McNaughton, Washington Forest Practices, 306-902-1669. Phone message exchanges in July.

- Washington is not now monitoring herbicides.
- Not aware of any historical information on implementation monitoring in Washington.
- A formal workplan for herbicide monitoring will be implemented in 2007, at a cost of $150,000 over six years.

Jerry Michael, Research Scientist, Southern Research Station, USDA Forest Service, Auburn University, 334-826-8700. August 20 and 29 phone conversations.

- BMPs are effective when properly applied, although accidents can happen.
- BMPs issues
    - *Timing of buffer delineation*: In South often lay out SMZs--based on observed presence of water--in autumn when weather cools and leaves have fallen so visibility through riparian forest better than in summer. But autumn is often end of multi-month drought, which reduces flows. Timber is harvested after SMZ delineation. Harvesting reduced evapotranspiration and increase streamflow. By spring, when herbicides are applied, have expanded water presence (vis-à-vis autumn buffer delineation) from combination of > ET (from harvest) and winter precipitation. BMPs could be improved to correct this problem.
    - *Width increase downstream inappropriate*: Common practice in South is to increase buffer width as stream widens downstream. This isn't appropriate for herbicides, although it may be for thermal (canopy) issues. Micheal installed buffers up to 0 order channel, where no scour could be seen. 35' SMZ' was as good as 100' SMZ.

- *Questionable relevancy of some fate/transport research*: Many herbicide fate and transport studies were done concurrent with US EPA's initial herbicide registration process, for some chemicals this was years ago. At that time uncertainty about maximum application rates for the "new" chemicals resulted in rates used in the fate and transport studies that in retrospect were too high (e.g., 3 or 4 times the currently allowable application rate). The results of those early fate and transport studies still showed chemical concentrations stream considerably below Health Advisory levels and toxicological triggers, implying low risk even at elevated application rates.
- *Compliance and effectiveness "inequities"*: Compliance and effectiveness are somewhat in the eye of the beholder; what's compliant to one person may not be to another. In Maine, for instance, local authorities set standards; practices that are effective in one political jurisdiction may not be in an adjacent jurisdiction with similar geomorphology, soils, and climate.

- Herbicide detectability in surface waters
  - Although they might not be detectable, herbicides commonly used in forestry will quite likely actually exist in surface waters because of their high water solubilities.
  - Conditions minimizing herbicide detectability:
- acidic soil—which hastens herbicide degradation
- fast-degrading herbicides
- dry weather within the first month after application—to lower chances of runoff or water reaching channels before the herbicide degrades into non-toxic compounds
- un-violated buffer
- sloppy sampling protocols (e.g., sampling at wrong time)
- Sedimentation
  - Worldwide the biggest water quality problem is sedimentation. Herbicide water chemistry impacts are ephemeral (lasting a few hours at most), and considerably below 48- or 96-hr toxicological triggers. The real issue is keeping sediment out of water. Herbicide use often produces sedimentation rates close to background rates whereas mechanical alternatives to herbicides can "result in 20 to 400% more sediment than observed on paired sites which were site prepared with herbicides" (Michael et al. 2000: Protecting surface water systems on forest sites through herbicide use. In 10th World Water Congress, 12-17 March 2000, Melbourne).

Eric Murray, Fish Biologist, NOAA Fisheries, LeGrande, OR, 541-975-1835 (ext. 222). October 6 phone discussion

- NOAA's Biological Opinion for BLM's Vale District states that monitoring results would be routed to Randy Tweten, at the LeGrande office. Eric Murray appears to be the actual contact for monitoring results. He stated that BLM had not yet routed monitoring results to him.

Dan Neary, Research Hydrologist, Rocky Mountain Research Station, USDA Forest Service, Flagstaff, AZ, 928-556-2176. August 29 phone discussion.

- Detectability of herbicides in surface waters is a function of the available technology. Instrumentation is now available to detect extremely low concentrations (e.g., parts per trillion) of chemicals.
- Herbicides can be detected in rainwater at these low detectability levels. Herbicides in rainwater probably are transported in by atmospheric processes.

- At these low concentrations herbicide-like chemicals are detectable in plants.
- At extremely low levels of detectability, the origin of the chemical is not possible to clarify; positive detection in surface water may be due to atmospheric deposition, not necessarily herbicide application.
- There is little available monitoring data for metsulfuron methyl and sulfometuron methyl from ground applications in forest streams with buffers. Neary did not think these two herbicides would not be detectable at operational levels of detectability (e.g., 1 part per billion).

Doug Parker, Regional Pesticide Coordinator, Southwest Region, USDA Forest Service, Albuquerque, 505-842-3280. July 8 phone conversation.

- Have herbicide BMPs but haven't done comprehensive monitoring or effectiveness research.

Jim Paul, Hydrologist, Private and Community Forestry, Oregon Dept. Forestry, 503-945-7487. September 9 e'mail.

- Bio-assessment: "My limited understanding of bioassessment procedures is that they are much less 'standardized' relative to procedures for water column sampling to assess herbicide movement into water bodies. Given the success of the recent ODF monitoring project on herbicide applications (ODF Tech. Rept 7, 3/00), ODF is likely to stay with the water column sampling approach in any future monitoring efforts. I would be curious, however, to see the results of your study to learn more about the spectrum of assessment procedures that are out there and how they compare to each other."

Dan Richter, Duke University, 919-613-8031. August 15 phone discussion on suggestion of Sam Austin.

- No information on/knowledge of herbicides.

Bob Rose, Salmon-Challis National Forest, 208-756-5152. July 17 phone discussion.

- The Forest hasn't done much monitoring and no data are available.

Gary Rule, NOAA, 503-230-5424. July 8 phone conversation.

- Doesn't think he knows enough about the topic to be helpful. Suggested other contacts.

Roger Ryder, Maine Division of Forestry, 207-731-7700. July 29 phone discussion.

- No monitoring by Main Div. Forestry for herbicide BMP implementation.
- Maine typically doesn't have forestry BMPs for herbicides.

Phil Schwolert, Colorado Department of Forestry, 970-491-7698. July 21 phone discussion.

- No monitoring of herbicide BMPs by the Dept. of Forestry.
- Contact Laurie Fisher, NPS Program Coordinator!

Ashok Shahane, Hydrologist, Bureau of Pesticides, Florida, 850-921-5434. August 5 phone discussion.

- Cropland focus, using detention ponds to reduce herbicide concentrations in citrus groves.
- Sent reprint of article entitled "BMPs and water quality at a Florida citrus grove site".

Jim Shepard, Manager-Sustainable Forestry & Wetlands Research, National Council of the Paper Industry for Air and Stream Improvement, 353-331-1745 ext. 227. August 12 phone discussion.

- On-going East Texas paired watershed study monitoring effects of herbicide application in coastal plain loblolly pine plantation.
    - Detection of glyphosate and imazapyr common in surface water in low ppb range.
- Modification of AgDrift chemical deposition model specifically for forestry.
    - Added forest buffers and more realistic chemical dissipation on uneven terrain.
- Information gaps
    - AgDrift needs field verification
    - Ephemeral streams—do they need to be protected? If yes, how to do it?
- Effectiveness assessment
    - Bioassessment is generally less expensive than water column sampling, but are the organisms really herbicide sensitive?
    - Similarity of pre/post biota richness, diversity, etc. is a strong argument that the practices work.
- General opinion on effectiveness of practices
    - Chemical levels are ephemeral (days or a few months at most) and are typical several orders of magnitude below biologically harmful concentrations.

Gene Skrine, Team Leader, Invasive Plants EIS Project, Portland, Oregon, 503-326-4310. September 8 phone discussion.

- No technical comments.
- Willing to route questionnaire to appropriate staff.

Elaine Snyder-Conn, FWS Refuges, Alabama, 251-441-5181. July 10 phone discussion.

- FWS preferences for herbicide application
    - For aerial applications, buffers are essential, especially for sensitive waters with listed species.
    - Asked for 300' buffers for cropland in general, but 500' for more toxic chemicals.
        - Rationale for 300' width
            - EPA studies found up to 8% drift within 50' of channel from 85' buffer, assuming somewhat unrealistic 8' helicopter height.
            - NRCS runoff studies incorporating surface flow and leaching identified effects within 75' of channel
    - Asked for low-drift nozzles (1/16" or greater nozzle diameter), low pressure application (40 psi of less for aerial and 20 psi or less for ground application), 7 mph or less wind speed if no inversion, 1-3 mph speed if inversion.
        - Aerial: flight line parallel to buffer, helicopter (not fixed wing), boom length no greater than 75% rotor span.
        - Ground: application no greater than 2' above plant, use lowest risk chemical that is efficacious.
    - Information need: data/models for combined herbicide runoff and drift movement through buffers.

Christopher Solloway, Assessment and Watershed Protection Division, Nonpoint Source Control Branch, U.S. Environmental Protection Agency, 202-566-1202. July 29 phone discussion.

- State chemical management BMPs are the most closely adhered to (by most operators) set of any BMPs.
- Cautions that compliance surveys may not provide abundant information.

- State forestry staff think chemical practices are implemented, better so than other types of BMPs
- Believes there are no significant problems with either implementation or effectiveness of herbicide BMPs at the industry level. Has less experience talking with smaller operators.
- Related information gap—effects of fire retardant for wildfire suppression.

Chic Spann, Regional Hydrologist, Southwest Region, USDA Forest Service, Albuquerque, 505-842-3255. March 14 e'mail exchange.

- Although the region did a BMP effectiveness study in the late 1990's, it did not address herbicides. No other information.
- Suggested other contacts.

Anne Strang, Maryland Forest Service Hydrologist, 410-260-8509. August 25 phone discussion.

- Last harvest BMP implementation survey was 6-7 years ago. Uncertain if it included herbicides.
- Planning monitoring of Chesapeake Bay forest lands to "double check" implementation.
- Generally happy with regulations, implementation and effectiveness of herbicide practices
    - Believes buffers are adequate.

Tom Suk, Staff Environmental Scientist, California Regional Water Quality Control Board Lahontan Region, 530-542-5419. September 24 phone discussion.

- No time to complete long questionnaire. Discussed short questionnaire.
- The Board does not monitor herbicides in water, but would if funds were allocated from the State of California to do so. The Board does require dischargers to monitor.
- BMP effectiveness
    - The Board has a zero detection standard. In 2002 Board staff gathered results of herbicide water quality monitoring and identified many detections. Consequently, BMPs are not effective in meeting the 0-detection standard.
    - Applicators follow product label direction, typically with no idea of the Board standard. Applicators think that by following label direction they are doing fine.
    - There is very high probability of herbicides reaching State waters in urban, forestry and noxious weed applications.
    - Currently the Board is attempting to educate applicators re the Board 0-detection standard and is pushing for less persistent and less mobile herbicides (not hexazinone).
    - Not aware of standard herbicide-specific BMPs or even application rates.

Tom Terry, Weyerhaeuser Company, Centralia, WA, 360-736-8241. September 15 phone discussion.

- Washington State Forest Practice Rules are mandatory. They are comprehensive, vary by herbicide and drive BMP implementation. Besides the Forest Practice Rules, product label and company regulations provide direction for herbicide application.
    - The Rules now require walking of stream (vs. aerial recon) to identify live water. This is an update/improvement from earlier (e.g., Rashin and Graber study in early 90s where live water received direct spray).
- Weyerhaeuser does detailed effectiveness (of herbicides, not of BMPs) surveys, but this information is not publicly available.
- Water quality monitoring isn't necessary based on studies in Oregon and Washington that showed general effectiveness with buffers narrower that currently in use.

- Pilots err on conservative side.

Jeff Vowell, Forest Hydrologist, Florida Division of Forestry, Tallahassee, 850-414-9935. August 12 phone discussion.

- Bio-assessment approach
  - Baseline macro-invertebrate samples were collected before herbicide treatment. Post-treatment samples were collected a couple of months after application, and after a couple of rain events but within the half-life of chemicals applied.
  - Would have missed any rain-induced pulse, but hopefully organisms would integrate effects over time.
  - Organisms are a better indicator of real ecosystem impairment than water column concentrations.
  - Bio-assessment is less expensive and easier in some ways to implement than water column sampling.
- Buffer width determination and effectiveness assessment
  - Satisfied that current widths are adequate because bio-assessment doesn't identify any problems.
  - Initial widths largely based on intuitive experience, then verified after buffers in place for a while.

Cliff Walker, FS Northern Region, Regional Office, Missoula, 406-329-3149. July 7 phone discussion.

- Montana Department of Natural Resources and Conservation, Forestry Division monitors BMP implementation (~50 practices) every two years with four teams including staff from various agencies. Pesticides/herbicides are typically addressed.
  - Contact Robert Ethridge, author of most recent Montana state implementation report.
- BLM and FS monitor per PACFISH and INFISH. Reports go to Boise
  - Contact Georgina Lampman (801-625-5358—FS Research).

Appendix B. Questionnaire Results

Several versions of the questionnaire were developed. An initial version was drafted and reviewed by NOAA Fisheries, BLM and FS oversight team members. This version was sent also to several FS personnel independent of the project for review. One of these reviewers recommended significant changes. Unfortunately, the earlier version of the questionnaire had been sent to several individuals before receipt of the final set of FS review comments. The two versions of the main questionnaire are similar and their differences do not contradict either version, but instead provide additional information. These versions are labeled July 28 and July 1 below.

We wanted feedback from as many individuals as possible and asked those with insufficient time to complete the 7/1 or 7/28 "long" versions of the survey to respond to the following questions:

A. Does your organization have herbicide BMPs in place for protecting water quality (yes/no)?

B. What type of herbicide application is used (air/ground)?

C. Does your organization monitor the aquatic effectiveness of the BMPs (yes/no)?

D. If so, how?

E. If so, what are the results of the monitoring (send documentation or describe)?

F. Do you believe that herbicide BMPs are effective for protecting water quality?

G. If not, why not?

Some individuals chose to respond to the questionnaire verbally. Those responses are incorporated into the Interviews (Appendix A).

Respondents:

David Bakke, Regional Pesticide-Use Specialist, Pacific Southwest Region, USDA Forest Service, California; 7/28 version

Susan Burch, Environmental Contaminants Program Manager, USDI FWS; 7/1 version

Lynn Danly, Rangeland Management Specialist, USDI BLM, Cottonwood Field Office, Idaho; 7/28 version

Jay Davis, Environmental Toxicologist, USDI FWS; 7/1 and short versions, hardcopy

Jerome V. DeGraff, Province Geologist, USDA Forest Service, California; 7/28 version

Eldorado Nat'l Forest (California); 7/28 version:

Robert Carroll, Silviculturist, Pesticide Use Coordinator
Dennis Haas, Culturist
Christine Mai, Hydrologist, Best Management Practices Evaluation Program
Chuck Mitchell, Soil, Water, Air and Geology Group Leader, Soil Scientist
Cheryl Mulder, Hydrologist, Herbicide Monitoring
Mike Taylor, Botanist, Noxious Weed Coordinator

Jim Frazier, Forest Hydrologist, Stanislaus Nat'l Forest, USDA Forest Service, California; 7/1 version

Frank Green, Staff Forester, Georgia Forestry Commission; 7/1 version, hardcopy

Anne Hairston-Strang, Forest Hydrologist, Maryland Department of Natural Resources, Forest Service, 7/28 version

Dr. George Ice, Principal Scientist, National Council of the Paper Industry for Air and Stream Improvement, Inc.; 7/28 version

Darryl Jones, Environmental Management Coordinator, South Carolina Forestry Commission; 7/28 version

Bill Lind, Fishery Biologist, NOAA Fisheries, Habitat Conservation Division; 7/28 version

Doug Parker, Regional Pesticide Coordinator, Southwestern Region, USDA Forest Service; 7/1 version

Assessment of Herbicide Best Management Practices:
BMP Effectiveness for Protecting Water Quality

Questionnaire (7/28/03)

Purpose

Determine expert opinions on the implementation and effectiveness of herbicide Best Management Practices (BMPs) for protecting water quality

Introduction

- A federal interagency group is assessing the effectiveness of BMPs for protecting aquatic resources from herbicide treatments. The primary focus is on noxious weeds in forest and rangeland riparian zones but information from agriculture, reforestation and other herbicide uses is relevant also. This questionnaire is one vehicle for obtaining relevant information.
- If you are short on time, please focus on the Application Procedures and Effectiveness questions.
- Don't hesitate to contact me with any questions (Neil Berg, 510-559-6426, nberg@fs.fed.us).
- To expedite your completion of this questionnaire, if documentation exists that answers any of the questions, send me the documentation and state "see documentation" as the answer to the question.

For this questionnaire—

- BMPs are broadly defined as management directions, formal BMPs, product labels or organizational policy/practices/protocols (e.g., Forest Practice Rules)
- Define implementation as doing what we said we'd do to protect water quality and effectiveness as how well water quality is protected by implementing the BMP(s).

Application Procedures

These "Application" questions should refer to the BMPs you address in the Implementation and Effectiveness questions below. If you have more than one purpose of the application, or more than one chemical, application mode or chemical type (questions 1-4), either list them all or list the single, most-commonly used purpose, chemical, application mode, etc. Base your answer to questions 5-29 on the chemical(s), application mode(s), or chemical type(s) listed in questions 1-4.

1. **Purpose of herbicide application?** Noxious weed abatement? Reforestation? Other? (underline, circle, check or describe if Other)?

   Bakke: Reforestation
   Danly: Noxious weed abatement
   DeGraff: Reforestation
   Eldorado NF: Reforestation, noxious weed abatement.
   Ice: I only apply a small amount of herbicides on my personal property but I do have significant experience with forest chemical application research and I'm involved in

herbicide/water quality modeling and studies. I will provide answers based on this experience. Applictions are for reforestation, site-release, and noxious weed abatement.

Jones: Reforestation (remove/reduce competing veg)

Hairston-Strang: Noxious weeds, reforestation, hardwood control after pine thinning

Lind: Noxious weed abatement and reforestation. Note: The info below pertains to how noxious weed treatments will be applied on the Payette National Forest, according to the biological opinion issued August 18, 2003. Many of the BMPs used were presented by the action agency as part of proposed action. http://www.nwr.noaa.gov/1publcat/bo/2003/200101363_fs_noxious_08-18-2003.pdf

2. **What chemical(s) (brand name(s)) is used?**

Bakke: Glyphosate, triclopyr, hexazinone

Danly: 2, 4-D, glyphosate, picloram, dicamba, clopyralid

DeGraff: Both Pronone and Velpar forms of hexazinone

Eldorado NF: Glyphosate (Accord, Rodeo, Roundup), Triclopyr (Garlon 4), Hexazinone, (Pronone 10G, Velpar L), Clopyralid (Transline)

Ice: Common silvicultural chemicals including glyphoshate, atrazine, 2,4-D, imazapyr, triclopyr, hexazinone, sulfmeturon.

Jones: Arsenal [imazapyr], Garlon [triclopyr], Chopper [imazapyr]

Hairston-Strang:

Weeds: Oust [sulfometuron methyl] most commonly, Transline [clopyralid] on thistle.

Pine plantation: Arsenal or Arsenal w/ Escort [metsulfuron methyl]/Oust for hardwoods & grass.

Phragmites (usually near water): Accord/glyphosate

Lind: Transline, Tordon 22K [picloram], Rodeo [glyphosate], Escort, Weedar 64 [2,4-D amine]

3. **Is the herbicide(s) applied by backpack, tractor/ATV, helicopter, fixed wing aircraft, other?** (underline, circle, check or describe if other)

Bakke: Backpack, helicopter

Danly: Backpack, ATV mounted spray tank, pickup mounted spray tank, helicopter

DeGraff: Backpack & helicopter

Eldorado NF: Backpack (90 percent or more of applications), belly grinder (granular form), ATV with a grinder attachment for granular. Tractor broadcast back in the 1970's with 2,4-D and diesel.

Ice: Most of my work has been with aerial application from helicopters but we also have information on ground-based applications, including work from a watershed study with banded backpack applications.

Jones: Aerial & ground using skidder-mounted sprayers

Hairston-Strang: Weed control for afforestation: usually tractor, spot spraying by backpack possible for maintenance. Hardwood control: usually helicopter with GPS/satellite positioning, some tractor (not at thin). Grass control: usually tractor with boom, spot spray with backpack

Lind: Hand-held spray nozzles attached to either backpacks, vehicles, or ATVs; Spot-gun sprayers mounted on ATVs; Hand-spreading granular formations; or wicking, dipping, painting, injecting individual target weeds.

4. **Is the chemical applied as a pellet, liquid, other?** (underline, circle, check or describe if other)

Bakke: Pellet, liquid
Danly: All a liquid formulation
DeGraff: Pellet, liquid
Eldorado NF: Liquid (one chemical or mix of two such as glyphosate and triclopyr), Pellet (only for Pronone 10G)
Ice: Most are applied as liquid but some Velpar (Hexazinone) is applied as pellets. Recent revisions to the AgDISP model allow aerial application of pellets to be modeled.
Jones: Granular or liquid, depending on site conditions & weather limitations
Hairston-Strang: Liquid
Lind: Most liquid formulations

BMPs

5. **Different states and organizations have different herbicide BMPs. What herbicide BMPs do you implement?** (e.g., buffers? prohibition of chemical directly onto surface water? weather criteria? other? Describe with specifics)

Bakke: Buffers, prohibition of chemical directly onto surface water, weather criteria. Refer also to QLG SEIS BMPs, can also send recent project-specific documents.
Danly: We implement a variety of BMPs which do include buffers for types of herbicide to be used next to streams and type of application methods to be used next to streams. We also implement BMP's to assure the herbicide application is effective such as use of colorants and wind and precipitation limits. We also have BMPs concerning herbicide storage, spill cleanup, transportation of herbicides, first aid, and safety equipment for applicators. Changes have been made to buffers beyond label requirements and standard protocols due to concerns by regulatory agencies. All our treatment areas are within watersheds containing habitat for anadromous fish. Expanded buffers are required even in streams not providing habitat but which drain into occupied habitat. BMP's are gleaned from the following documents.

BLM Handbook H-9011 Chemical Pest Control – implements protocols concerning transportation of herbicides, safety for operators, storage and handling, safe application by both ground and aircraft, spill contingency, first aid, environmental considerations, and application guidance.

Environmental Impact Statement Vegetation Treatment on BLM Lands Idaho Decision 1991 – Project Design Features for Herbicide Treatment page 1-33 to 1-43. Provides general best management practices for treatments.

Biological Assessment of 2003 Noxious Weed Control Program for Federally Listed and Candidate Species – Most numerous and restrictive set of protocols. Most standard operating procedures are from the previous documents with additional buffers and reporting requirements. (Cottonwood Field Office USDI-BLM)

DeGraff: Protection of groundwater
Eldorado NF: Practice 5-7 - Pesticide-Use Planning Process

ID team identifies sensitive areas to avoid or other concerns. This process allows the team to assess the practicality of treatments, assess the degree of risk involved, and set forth means of avoiding adverse effects.

Practice 5-8 - Pesticide Application According to Label Directions and Applicable Legal Requirements

All herbicide applications adhere to applicable state laws, Cal EPA regulations and safety regulations, and label directions for application rates and methods, mixing, and container disposal.

Practice 5-9 - Pesticide Application and Monitoring and Evaluation

A water quality-monitoring plan is always implemented although occasionally the plan may call for no sampling. Forest Service personnel (such as botanists, culturists and silviculturist) will monitor effects on non-target plants after application and/or monitor effectiveness of treatment. Prior to the start of application, all application equipment will be calibrated to insure accuracy of delivered amounts of herbicide. Periodically during application, equipment will be rechecked for calibration. Colorants or dyes will be added to the herbicide mixture to determine placement.

Practice 5-10 - Pesticide Spill Contingency Planning

A spill plan is developed for herbicide treatments and reviewed by all Forest Service employees involved in the project, as well as by the contractor and the appropriate forest and district staff and line officers. Any herbicide application contract will contain clauses that will minimize the chances of herbicide spills (such as designating routes of travel and mixing sites, minimizing herbicide mix in tanks while traveling between units, requiring a separate water truck from the batch truck), and if a spill occurs, outlining responses required by the contractor. Spill kits will be required in Forest Service and contractor vehicles on site and where contractor-supplied herbicides are stored. Designated travel routes are important when traveling through residential developments to the site or when there are concerns about the proximity to a water body or stream course that may be populated with TES species. Water may be drafted on National Forest land, but only at sites designated by COR. Contractor must have separate vehicle (from batch truck) for drafting water.

Practice 5-11 - Cleaning and Disposal of Pesticide Containers and Equipment

All herbicide and adjuvant containers will be triple rinsed, with clean water, at a site approved by the Contracting Officer or Representative, or, in the case of application by Forest Service personnel, approved by the project director. Disposal of non-recycled containers will be at legal dumpsites; certification of such disposal will be required prior to final payment on contract applications.

Practice 5-12- Streamside Wet Area Protection During Pesticide Spraying

Untreated buffer strips would be established on stream course and along water features based on environmental analysis. For ephemerals the buffers vary from none up to 10, 25 or 50 ft. Buffers have always been applied on the Eldorado National Forest but have changed through the years based on monitoring results or concerns based on changed circumstances.

Practice 5-13 - Controlling Pesticide Drift During Spray Applications

To reduce off-site and off-target drift several measures have been placed into the contract and project plans. Among them are: 1) using ground application equipment, specifically backpack sprayers; 2) ceasing application when weather parameters exceed label requirements, precipitation, or forecast of greater than a 70% chance of precipitation in the next 24 hours; 3) requiring a spray nozzle that produces a relatively large droplet; 4) requiring low nozzle pressures (15 psi); 5) requiring the spray nozzle be kept within 24 inches of vegetation being sprayed; 6) requiring a pressure gauge or pressure regulator on the backpack sprayers; and 7) requiring a directed spray away from water or from conifer seedlings and oaks as well as the use of physical barriers; and 8) requiring the use of a seedling wash-down solution for accidentally oversprayed seedling.

Ice: There are four levels of BMPs that are commonly applied to industrial forest sites. First, the label requirements are met. An example is the label for Accord that states that operators should "Avoid drift..." and the label for Arsenal that operators should "Maintain adequate buffer zones to insure that drift does not occur off the target site." Note: Labels may have been updated since this language was used. Second, in states with forest practice regulations, those regulations are followed. So for example, the

Oregon Forest Practices Act regulations require a 60-foot buffer along type D (domestic water supply) and F (fish bearing) streams. Both these are absolute limits to company operators and contractors. There are also operational limits set by the states (wind speed, humidity, etc.). Companies often have their own policies about chemical applications that will meet or exceed the state and label requirements. Finally, in some cases, companies may use the AgDRIFT or AgDISP models to calculate equivalent or better protection using alternative BMPs. Some companies, for example, routinely use very coarse nozzles and can achieve equal or better drift control than the default values based on state guidance limits.

Jones: Our BMPs address streamside management zones adjacent to perennial streams, intermittent streams, ponds, and lakes. Our BMPs state that chemicals should not be applied directly to water bodies unless specifically labeled for that purpose. Weather restrictions apply to both aerial and ground applications, specifically related to wind speed. Specific restrictions are:

- Follow label directions and applicable state and federal laws in the storage, transportation, handling, and application of all pesticides.
- Obtain MSDS sheets from the manufacturer for toxicological information and personal safety protection requirements.
- Apply restricted use pesticides only under supervision of a certified pesticide applicator.
- Aerial application should be done only when wind speeds are 5 mph or less for liquid formations and 8 mph or less for granular formations.
- Ground application should only be done when wind speeds are 10 mph or less.
- All on-site pesticide handling should be done away from streams, lakes, ponds, or drainage areas.
- Dispose of pesticide containers and/or excess pesticides according to state and federal regulations.
- Clean up and/or contain all pesticide spills immediately and comply with state and federal regulations concerning reporting spills of hazardous materials.
- Avoid applying pesticide directly to water bodies unless specifically prescribed and approved for aquatic management needs.
- Avoid broadcast application of pesticides within primary streamside management zones
- Avoid applying any herbicide adjacent to the primary SMZ that would damage trees in the primary SMZ.

Hairston-Strang: Product label restrictions are the most widely used, including not spraying onto surface water, spraying in still (0-4 mph) conditions, notification, mixing, container disposal, and types of vegetation being controlled. State contracts for coordinated spraying of private land add some specifications. State lands also use buffers, which can differ by management unit and agreement of the interdisciplinary team reviewing the management plans. Most herbicide spraying is occurring on private lands, with some on Chesapeake Forest and other Eastern Shore State Forests. CF lands are using buffers of 150 to 300 feet.

Lind: All of the above, see pages 5 – 8, and 50-51 of the above referenced biological opinion

6. **How do you determine what BMPs to implement?** (underline one or more: herbicide label direction, state regulation, organization directives, other (specify))

Bakke: All of these, plus rely on history of what has worked since early 1990's.

Danly: Initially, BMPs were prescribed in our EIS which allowed us to conduct herbicide treatment on Federal lands. We also were trained on proper herbicide application through

BLM's EPA approved certification process. All herbicide applications on BLM managed lands must be overseen by a person who has been certified through this class. Since it is federal law that each herbicide be applied in accordance with the label, the applicator follows the label requirements during an application.

Since listing of the anadromous fish species, we have also conducted consultation with NOAA fisheries and FWS. This has been a morphing process with morphing final outcomes as far as buffers and prescribed mitigation. Presently we are implementing very stringent buffer widths above what is prescribed on herbicide labels and our standard BLM protocols.

DeGraff: State regulation & prohibition in Record of Decision for Pacific Southwest Region Vegetation Management EIS against applying hexazinone to soils where it could enter groundwater.

Eldorado NF: All of the above. The Eldorado National Forest follows herbicide label directions, all applicable state regulations, and additionally, any national, regional, and local organizational directives. All herbicide applications are governed by NEPA and the BMP's are generally built into the NEPA Document.

Ice: All of the above and in some cases modeling.

Jones: Label directions, state regulation, & site-specific conditions, for example- whether or not a perennial or intermittent stream is present significantly impacts whether or not SMZs must be delineated before herbicide application begins.

Hairston-Strang: Herbicide label direction, state regulation, organization directives. Label specifications are the most important control on use because they are the most widely used and specific to the type of chemical and its attributes.

Lind: Combination of the above

7. If you install buffers, how do you determine that buffers are needed?

Bakke: Initially driven by biological concerns of potential effects; actual need for any individual unit is determined based on location of nearby water, topography, weather, stream classification (Class 1, 2 or 3)

Danly: Based upon presence of sensitive areas, mainly streams or sensitive plant populations. The most stringent buffers and therefore, the ones we are required to use were begrudgingly agreed upon at level one meetings in order to achieve concurrence on our noxious weed control program.

DeGraff: Blank

Eldorado NF: During the Environmental Analysis (EA) process, interdisciplinary team members make recommendations based on risks of adverse effect to beneficial uses of water, and project objectives. The buffer widths are set by the deciding official, based on recommendation from an hydrologist, silviculturist and/or fisheries biologist. These would remain in effect for the project length, although changed circumstances could alter them (examples of changed circumstances could be new laws and/or regulations including additions to the TES species list, changes in organizational policy, or on the ground changes due to natural events, or effects substantially different from predictions in the EA). Widths of buffer strips are based on a combination of factors including the chemical properties and the labeled use of the herbicides being used, beneficial use of the water feature, and results from previous water monitoring. Buffer widths have been based on stream class (I, II, III, IV), stream type (perennial, seasonal, ephemeral), proximity to water feature (spring, reservoir, lake), and the beneficial water use of that specific feature or stream reach (domestic, municipal water, aquatic frog habitat, trout fisheries, etc.). Results from water monitoring from previous years' herbicide application

programs on the Eldorado National Forest determine whether the buffers have protected water quality.

An example of a changed circumstance that occurred on the Eldorado National Forest was the 1996-97 storm events and resultant landslide activity in the South Fork American River canyon and Cleveland Fire area. Any proposed projects including herbicide application that could affect land stability were reviewed by the forest geologist and a hydrology review was also conducted to identify new hydrologic features, changes in channel morphology, and to assess the adequacy of the buffers used. Geologic and hydrologic reviews of herbicide treatments in the Cleveland Fire area were recommended on an annual basis and any units proposed for herbicide treatment that lie adjacent to or contain active landslide features were assessed in the field.

Buffer strips currently used on the Eldorado National Forest:

Buffer Strips

Stream class for	**1***	**2***	**3**	**4**	**Wet area, springs, meadows,**
Glyphosate (Accord)	50 feet	25-50 feet	25 feet	0-10 feet**	25 feet
Glyphosate (Rodeo)	0 feet	0 feet	0 feet	0 feet	0 feet
Clopyralid	75 feet	50 feet	25 feet	0 feet	50 feet
Triclopyr	100 feet	50-100 feet	50 feet	25 feet	
Hexazinone	200 feet	100-200 feet	100 feet	50 feet	

*on large class 1 and 2 streams where a flood plain exists, increase buffers to stay out of the flood plain.

**25 feet where riparian vegetation or running water is present.

Ice: Again, the forest practice regulations, label requirement, company directives, and in some cases, modeling.

Jones: The need for buffers is determined by the type of water body present. Perennial streams, ponds, and lakes require a 40' forested primary SMZ and a secondary SMZ determined by slope. Intermittent streams require a 40' primary zone with the root mat, forest floor, and understory vegetation intact, and a secondary zone determined by slope.

Hairston-Strang: Beyond restrictions on the label, they are set by the landowner or land manager. For Chesapeake Forest lands, the management plan specifies 150 foot buffers, with 300 foot buffers in more sensitive areas like Endangered Species Areas. Spray buffers are also established at 25 feet for adjoining property boundaries and roads. For private land spraying coordinated by DNR, the contract specifies GPS coordinates (obtained from the ground) to identify exact spray locations and buffers.

Lind: Based on literature review and review of Forest Service Risk Assessment Documents

8. **If you install buffers, how do determine buffer width?**

Bakke: Aerial – minimum specified in Regional Reforestation FEIS; site specific analysis usually involves AgDrift or AgDisp deposition modeling. Ground-based – based on past experience and monitoring results.

Danly: In our Biological Assessment for our noxious weed control program, we have buffers for intermittent and perennial streams and mainstem rivers. We also have buffers from known T&E plant species.

DeGraff: Blank

Eldorado NF: Buffers are flagged out. Distance is by ocular estimate, periodically verified with tape or ocular estimate that might err toward the benefit of a wider buffer.

Ice: All of the above but at least the forest practice regulations

Jones: Buffer width is determined by the slope adjacent to the stream or water body. If the slope is >5%, then a secondary zone is required. Additional SMZ width is also required if trout waters are present.

Hairston-Strang: Label restrictions determine some; others are added as operational standards. On Chesapeake Forest, buffers are set in the management plan, which can be adjusted through the interdisciplinary team process, along with consideration of research and precision for application equipment/techniques.

Lind: Buffer width varies dependent upon application method, wind speed, and toxicity of chemical proposed.

9. If you specify nozzle type and orientation, what are they and how do you determine them?

Bakke: All aerial has been granular, so nozzles not specified. Ground based - contracts talk to large droplets and low pressure systems; if nozzles are specified they are also qualified (with wording like "or equivalent").

Danly: N/A

DeGraff: Blank

Eldorado NF: For broadcast applications TEEEjet 8004 is used. This spray results in large droplet sizes at the low pressure we use, but enough liquid volume to not slow down the operator. For low volume basal application, less fanning occurs and the spray is focused in one area, which reduces any over spray. For basal application of triclopyr, we have used an adjustable cone nozzle which places more chemical on the plant with less over spray or actually painted the chemical on with a brush or dauber.

Ice: In Washington there are limits on the nozzle types unless an alternative plan is submitted. Companies must assess whether they can achieve adequate coverage with nozzle types and orientations or whether stripping will be too severe. This is weighed against drift control options

Jones: N/A

Hairston-Strang: The spray contract (attached) used by the State for the coordinated private land spraying and State work specifies a microfoil boom with .028 nozzles for helicopter spraying, along with the position control requirements. If greater directional control than possible by helicopter is needed, ground application is used.

Lind: Nozzles with large orifices to deliver a median droplet diameter of 200-800 microns was specified, where droplet size is thought to be large enough to avoid excessive wind drift while providing adequate coverage of target vegetation.

10. If you have weather criteria, what are they and how do you determine them?

Bakke: Wind speed limitations, don't spray if rain is imminent (normally 70% within 24hour window); for certain formulations of triclopyr there is usually a temperature and relative humidity restriction as well, to protect against volitization.

Danly: Weather criteria include wind speed limits for certain application methods, avoiding application during precipitation events and if possible directly before precipitation. These criteria were first prescribed in BLMs handbook 9011 "Chemical Pest Control". All crews carry a wind meter and thermometer.

DeGraff: Blank

Eldorado NF: Weather criteria are specified in the EA (organizational policy), label, and state regulations. We monitor weather using National Weather Service daily forecasts. Current weather status is field verified using thermometers, anemometers, visual, wind gauges and relative humidity from morning fire weather. When forecasts and/or field observations dictate, applications are altered by suspending operations (for precipitation forecasts exceeding criteria and wind exceeding criteria), moving to sheltered areas (for wind exceeding criteria in current application area, but not in another), or changing herbicides if possible (when temperature criteria is going to exceed label for current herbicide being used (applicable to Garlon). Wet weather is usually preceded by unacceptable winds so we would have shut down any way.

Ice: State forest practice rules. In some cases we have recommended that companies adopt their own, more stringent weather criteria, to allow for equal drift control with narrower buffers.

Jones: Weather criteria are primarily related to wind speed. Aerial application should be done only when wind speeds are 5 mph or less for liquid formations and 8 mph or less for granular formations. Ground application should only be done when wind speeds are 10 mph or less.

Hairston-Strang: Still winds, not raining, the necessary conditions to avoid drift and movement of herbicide. Determined according to the label, usually, since products' mobility differs.

Lind: Various BMPs dependent upon wind speed; no spraying if 1) precipitation is occurring or is imminent (within 24 hrs); 2) air turbulence is sufficient to affect the normal spray pattern; 3) snow or ice covers the target foliage; 4) no herbicide application by any method would be authorized if winds exceed 15 mph. Also, during application, weather conditions will be monitored hourly by trained personnel at spray sites.

11. If you have drift criteria, what are they and how do you determine them?

Bakke: Drift is dealt with through buffers, there are no separate criteria.

Danly: N/A

DeGraff: Blank

Eldorado NF: Actions to minimize drift include requiring a spray nozzle that produces a relatively large droplet; require the spray nozzle be kept within 24 inches of vegetation being sprayed; directional spraying (or covering of seedling) to avoid seedlings and/or water (when in the proximity of water), and adhering to label and organizational direction for wind speed. These are in effect for all projects. When drift possibility becomes an issue, mainly due to wind, actions taken can include suspending operations, moving to sheltered location, and/or moving to vegetation type with less drift possibility (shorter vegetation). Drift can be monitored by using colorants in the mix.

Although Rodeo is approved for aquatic application, additional protection measures were designated for this chemical when applied for knapweed control along the South Fork Silver Creek on ENF. It was only applied to emergent plants, on dry ground, and in a manner that prevents the spray from being applied to the water. Additional measures included: not applying herbicide to the water surface, including standing water; when getting close to surface water, the applicator will direct the nozzle away from the water and will only apply herbicide if the wind is still or blowing from the water to the applicator. If the wind if blowing from the application site to the water, herbicide will not be applied.

Ice: There are no formal criteria. Generally looking for a 95 percent reduction in the application rate to reach the streams (there is a dramatic law of diminishing returns above

this level of reduction) or a 90 percent reduction in application rate reaching the riparian vegetation (where significant damage to riparian vegetation is expected to not occur).

Jones: Blank

Hairston-Strang: Same

Lind: Only very low risk, or "aquatic approved" chemicals (glyphosate or Rodeo) will be used within 15 feet of open water; no spraying of persistent herbicides (Tordon) will be authorized within 100 feet of live waters; herbicide spraying within 100 ft of live water will not be authorized when wind speed exceeds 5 mph; no spraying will be authorized when wind speed exceeds 8 mph; no herbicide application at all will be authorized when wind speed exceeds 15 mph.

Implementation Monitoring

If you (or your organization) do aquatic BMP implementation monitoring for herbicides, continue with the Implementation section. If you do aquatic BMP effectiveness monitoring for herbicides, but not implementation monitoring, go to the Effectiveness section. If you do both, continue with the Implementation section. See Introduction for definition of implementation.

12. How do you determine herbicide treatments/sites/projects for implementation monitoring?

Bakke: All units that are treated have inspectors that monitor applications through the time it takes to complete, so in essence, all units are monitored to some extent for implementation.

Danly: Many of our treatments are almost a reach as far as potential impacts. i.e. small total acreages within a watershed and treated upon an upland. Therefore, we only do implementation on a couple of projects where the acreages treated were mostly with an HCRA.

DeGraff: Blank

Eldorado NF: Generally, every project with a contract is monitored. Inspectors and/or contractor's officer representatives are on site 100 % of time. These people install buffers, flag out unit boundaries, monitor the application crew for compliance with the contract, and inspect work for proper coverage. They instruct the crew and crew foremen prior to application of the provisions in the contract to protect sites. A federal employee is present at batching, inspectors follow crew to assure compliance, and to direct applicators, if needed.

During force account work, each project is under the direction of an employee with a state Qualified Applicator's Certificate or License (QAC or QAL).

All release and site prep units are tracked in SRS with information that includes where, what chemical, and rate of application. Also, silviculturists regularly walk the units which have been treated to determine needs for re-treatment and for the timing of these treatments.

The botanists monitor sensitive plant populations to make sure they were avoided and include documentation only when accidental spraying of sensitive plants has occurred. For noxious weed treatment, monitoring determines the efficacy of the herbicide treatment which may be followed-up with hand-pulling of missed plants -- or if missed individuals are not flowering – another glyphosate treatment may be applied (to ensure no seed is produced). The Yellow Starthistle Control Project EA stated that after the Transline application the treatment areas would be monitored and stragglers/missed plants would be treated with glyphosate or hand pulled if seed had formed.

Ice: We have been involved is some monitoring, both collection of water samples with herbicide applications and even some use of tank-added fluorescent dyes to track inadvertent introduction to streams. These studies show, like the monitoring reported by state forestry agencies, that herbicides tend to last only short times in streams. Highest concentrations and greatest persistence in runoff can be expected for the smallest streams.

Jones: Sites for inclusion in monitoring are randomly selected from the air. Our monitoring process begins by selecting a statistically valid number of recently harvested sites. These sites are evaluated for BMP implementation, then re-evaluated both one year and two years post-harvest for compliance with site preparation BMPs, if site prep is conducted at all. A portion of these sites are chemically site prepared, and those are evaluated for compliance with our BMPs for chemical site prep.

Hairston-Strang: No formal monitoring protocol- just operational oversight by land managers for herbicide applications

Lind: The Payette NF doesn't do implementation monitoring at this time

13. **Is there a statistical component to the selection process** (if yes, describe)?

Bakke: No

Danly: No

DeGraff: Blank

Eldorado NF: Generally, 100 % of contract work is monitored as described above. Force account work is not monitored similarly, but is under direction of QAC or QAL.

Ice: Blank

Jones: A statistically valid number of monitoring sites is determined for each monitoring survey. Once that number is determined, the number of sites needed in each county is determined based on the bi-annual wood product output (for example, if 20% of the wood harvested in FY 2002 came from Anderson County, then 20% of our monitoring sites will be located in Anderson County). At least twice as many sites as is necessary are located from fixed wing aircraft for each county. A computer is then used to randomly select the actual monitoring sites from that pool.

Hairston-Strang: No

Lind: Blank

14. **Is there a QA/QC component to the selection process** (if yes, describe)?

Bakke: No

Danly: Questions ask whether the activity occurs within a watershed containing habitat for listed species.

DeGraff: Blank

Eldorado NF: No

Ice: QA/QC is always part of our study design.

Jones: BMP Foresters are instructed to locate a particular number of sites for each county. The program coordinator uses a computer to randomly select monitoring sites from those selected by the BMP Forester.

Hairston-Strang: No

Lind: Blank

15. **Are there weaknesses in the site selection process** (if yes, describe)?

Bakke: Blank

Danly: No

DeGraff: Blank
Eldorado NF: No
Ice: Some of this monitoring has been on an opportunity to monitoring only basis. We have not statistically sampled monitoring sites.
Jones: No
Hairston-Strang: NA
Lind: Blank

For aerial applications (#16-23):

16. **How do you determine if buffers with the correct width are installed** (e.g., spray cards at edge of buffer, other (specify))?

Bakke: Spray cards. Also by walking the stream or being in close proximity to streams while application is occurring – i.e., visual inspection.
Danly: Post treatment monitoring, Visual Observation
DeGraff: Blank
Eldorado NF: Blank
Ice: Damage to vegetation.
Jones: Visual observation during multiple field visits to the site.
Hairston-Strang: Visual observation
Lind: Blank

17. **How do you know if the correct flight path direction and height are implemented** (e.g., visual observation, other (specify))?

Bakke: Visual observation.
Danly: N/A
DeGraff: Blank
Eldorado NF: Blank
Ice: Direct observation of operations.
Jones: Visual observation.
Hairston-Strang: Visual observation
Lind: Blank

18. **How do you know if the correct nozzle type/orientation is implemented** (e.g., direct inspection, other (specify))?

Bakke: Direct inspection.
Danly: N/A
DeGraff: Blank
Eldorado NF: Blank
Ice: Visit helicopter or contractor report.
Jones: Not specifically evaluated in our monitoring.
Hairston-Strang: Specified in contract, foresters oversee application
Lind: Blank

19. **How do you know if the location of surface water is correctly identified** (e.g., aerial inspection, walking stream, other (specify))?

Bakke: Aerial inspection, walking stream. Prior to application, recon flight.

Danly: Topo maps, visual observation of riparian vegetation. Basically an assumption from the air that if there is standard riparian vegetation there is or will be water present.
DeGraff: Blank
Eldorado NF: Blank
Ice: Fly over prior to spray operation.
Jones: Walking the stream and inspecting the site during multiple site visits, combined with conversation with the forester supervising the operation.
Hairston-Strang: On-site inspection prior to the contract, GPS buffer boundaries to coordinate with helicopter GPS
Lind: Blank

20. **How do you know if weather condition criteria are correctly implemented** (on-site gauging of relative humidity, wind speed and direction, other (specify))?

Bakke: On-site gauging of relative humidity, wind speed and direction.
Danly: Applicator records temperature, wind direction and speed at various intervals and includes on application records. In addition, common sense dictates the chemicals are ineffective and therefore wasted if not applied properly. Contractors have it in their best interest to assure an application is done correctly so he/she gets a return job. Many of our projects are accomplished through a cooperative weed management area project. A county weed control person is on site at all projects assuring BMP's are implemented. BLM observers can also spot check the operation.
DeGraff: Blank
Eldorado NF: Blank
Ice: Blank
Jones: Not specifically evaluated in our monitoring.
Hairston-Strang: Blank
Lind: Blank

21. How do you know if the correct chemical application rate is used?

Bakke: Direct inspection.
Danly: Applicators are all certified and do this for a living. They know the acreage treated, amount of chemical used over that acreage and can re-calibrate at each load if application rates appear to be off.
DeGraff: Blank
Eldorado NF: Blank
Ice: Blank
Jones: Conversation with the forester supervising the operation.
Hairston-Strang: Applicator liability and guarantees
Lind: Blank

22. How do you know if the correct storage, handling, transport procedures are implemented?

Bakke: Direct inspection.
Danly: Applicators are all certified and know requirements. Contractors can also be spot checked to assure they are not within mixing and loading buffers. Many times, transportation and storage are not under BLM control as the projects are part of a county-wide operation.

DeGraff: Blank
Eldorado NF: Blank
Ice: Blank
Jones: Site visit and conversation with the forester supervising the operation.
Hairston-Strang: Forester oversight
Lind: Blank

23. **If you have other BMPs for aerial application, list them and explain how you know if they are implemented correctly.**

Bakke: Blank
Danly: Blank
DeGraff: Blank
Eldorado NF: Blank
Ice: The use of half-booms near streams is becoming more common.
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

For ground applications (#24-29):

24. **How do you determine if buffers with the correct width are implemented** (e.g., spray cards at edge of buffer, other (specify))?

Bakke: Buffer widths are double-checked during project layout and once again immediately prior to treatment.
Danly: The main method of implementation is proper training of application crews so they know the herbicide and application buffers. Buffers were in place before requirements for consultation as standard environmental protocols. Just because we have endangered species now, does not mean agencies have just started implementing safe standards. Applicators also record the details of the herbicide project on treatment records. Most noxious weed control is accomplished by spot spraying of target weeds. Use of spray cards at the edge of buffers would be time consuming and not relevant, especially in a spot spray situation. Proper training and trustworthy employees are the way we determine correct implementation.
DeGraff: Blank
Eldorado NF: During application colorant in the chemical mix can indicate correct placement. Applicators use dye in the mix and visual inspection by on-site inspectors during application verifies correct placement of chemical outside of the buffer. Buffers are designated with plastic flagging. Post- application, dead or dying vegetation can reveal extent of application.
Ice: Vegetation response.
Jones: Visual observation during multiple field visits to the site.
Hairston-Strang: GPS coordinates and satellite positioning help direct application to very specific locations
Lind: Blank

25. **How do you know if weather condition criteria are correctly implemented** (on-site gauging of relative humidity, wind speed and direction, other (specify))?

Bakke: On-site gauging of relative humidity, wind speed and direction

Danly: Each treatment is accompanied by documentation. The properly filed out application record records weather conditions, application rates, applicators etc. These treatments forms are required documentation in place as a result of BLM protocols developed prior to 1980. All offices where herbicides are used should be keeping these records. This documentation did not result from any regulatory oversight of NOAA Fisheries or FWS.
DeGraff: Blank
Eldorado NF: Contract inspectors are on site during application. They monitor weather through the use of instruments and direct contractor when criteria exceed parameters. During force account work project leader (QAC or QAL) performs the same duties.
Ice: Blank
Jones: Not specifically evaluated in our monitoring.
Hairston-Strang: Forester oversight at time of spray
Lind: Blank

26. **How do you know if the correct nozzle type/orientation is implemented** (e.g., direct inspection, other (specify))?

Bakke: Direct inspection
Danly: N/A
DeGraff: Blank
Eldorado NF: Inspectors check the contractor's equipment before work begins, at the beginning of project, during the progress of the contract and when equipment changes to insure proper application.
Ice: Blank
Jones: Not specifically evaluated in our monitoring.
Hairston-Strang: Forester oversight at time of spray
Lind: Blank

27. How do you know if the correct chemical application rate is used?

Bakke: Direct inspection
Danly: Applicators are all properly trained in mixing and calibration. They frequently check their equipment calibration and adjust if they suspect the equipment is not properly calibrated. The application records also record the amounts of chemical used and acres treated. Applicators and supervisors can check these records to further assure proper calibration and therefore application rates.
DeGraff: Blank
Eldorado NF: We observe batching operation (require unopened containers) for correct mix. We base this calculation on the amount of coverage we achieve and the gallons used on each acre. We determine rates of coverage by dividing total gallons of mix used on a unit by its area. This determines rate per acre on a unit basis, which is the smallest unit we use. We also monitor the application in progress to insure proper coverage.
Ice: Blank
Jones: Conversation with the forester supervising the operation.
Hairston-Strang: Specified in contract and checked to the extent possible during spray jobs by foresters overseeing job
Lind: Blank

28. How do you know if the correct storage, handling, transport procedures are implemented?

Bakke: Direct inspection
Danly: Again, proper training of personnel. Most storage, transport, and handling procedures have been implemented for some time.
DeGraff: Blank
Eldorado NF: While on National Forest System lands, compliance with these procedures is accomplished with contract inspectors or COR. Procedures are specified in the contract. Inspectors and/or contractor's officer representatives are on site 100 % of time. We inspect the storage facility before work commences and have the opportunity to re-inspect at any time.
Ice: Blank
Jones: Site visit and conversation with the forester supervising the operation.
Hairston-Strang: Forester oversight at time of spray
Lind: Blank

29. If you have other BMPs for ground application, list them and explain how you know if they are implemented correctly.

Bakke: Blank
Danly: Blank
DeGraff: Blank
Eldorado NF: If we need other BMPs or standards, then they will be placed in a contract clause or in the EA.

There are a number of Framework standards [from Sierra Nevada EIS] within the Riparian Conservation Objectives (especially Objective #1 and 4) that need to be acknowledged such as not spraying in TES amphibian habitat, use of low velocity pumps, requiring screens to be placed over the hoses for drawing water due to the potential presence of frog/fish larva in ponds and waterholes, etc.

Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

30. **Describe any weaknesses or difficulties in assessing the implementation of any particular BMPs** (e.g., identifying presence of surface water in heavily vegetated channels).

Bakke: Identifying presence of surface water in heavily vegetated channels. This is why the Region implemented a policy with aerial applications of hexazinone where there have to be assurances that all potential water sources are identified and flagged (buffered); if this assurance cannot be made, then aerial hexazinone is not allowed.
Danly: Blank
DeGraff: Blank
Eldorado NF: Usually potential wet areas are inspected during the layout for the contract and the contractor and his crew have instructions on how to prevent mishaps. Rarely in heavily vegetated areas, seeps may not have been identified and flagged out. In contract applications, applicators are instructed not to spray if they encounter water and to notify Forest Service. In this situation, by the time an applicator may see water, they may already be within what would be the buffer distance.
Ice: Several years ago we proposed a study to use thermal images to detect surface waters in heavily vegetated channels. This study was never undertaken. We are also working to

document the filtering effect of vegetation on drift near streams and we would expect the types described above to have significant reductions in deposition.

Jones: Timing of site visits can make it hard to evaluate- if the site visit is too soon after application, herbicide effects may not be apparent.

Hairston-Strang: Blank

Lind: Blank

Results: rate of implementation for herbicide BMPs (#31-33)

31. **How are implementation rates specified** (what metric(s) are used—e.g., percent implemented properly)?

Bakke: Blank

Danly: I guess it all comes down to how much you trust your applicators. We properly train and spot check personnel. They are implementing BMP's as we train them to. I'm not sure how you document their activities 100% other then trust their records and competence .

DeGraff: Blank

Eldorado NF: See #12

Ice: Blank

Jones: Percent implemented properly, and no evidence of water quality impact.

Hairston-Strang: No quantification of rates

Lind: Blank

32. Can you send me a copy of documentation of recent results?

Bakke: Blank

Danly: Blank

DeGraff: Blank

Eldorado NF: We have daily diaries documenting some of the results (moving to other units due to wind, stop work orders for precipitation, etc).

Ice: Blank

Jones: Most recent publication is available online at www.state.sc.us/forest . Data from the most recent monitoring survey is currently being analyzed for publication.

Hairston-Strang: Blank

Lind: Blank

33. If you know of other data on implementation rates (beyond your own), give contact information for the keeper of the other data.

Bakke: Blank

Danly: Blank

DeGraff: Blank

Eldorado NF: Unknown

Ice: See L. Dent and J. Robben. 2000. Oregon Department of Forestry: Aerial Pesticide Application Monitoring: Final Report. Oregon Department of Forestry Technical Report 7, Salem, OR.

Jones: Blank

Hairston-Strang: Blank

Lind: Blank

34. List any information or knowledge gaps re assessment of herbicide BMP implementation for aquatic resources.

Bakke: Blank
Danly: Blank
DeGraff: Blank
Eldorado NF: Blank
Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

Effectiveness Monitoring

See Introduction for definition of effectiveness.

Eldorado NF: The water sampling that we do is under effectiveness monitoring, which gives us an indication that buffers and other measures are adequate in protecting water quality.

35. Describe how sites are selected for effectiveness monitoring, including statistical approach if used.

Bakke: Risk and likelihood of detection; not statistical.
Danly: Post monitoring is done on every site. We look for non- target vegetation effects, effective treatment results, etc.
DeGraff: Based on placing of monitoring wells near or just down slope from units where hexazinone was to be applied, usually just upslope from major stream. Number of sites was based on physical limitations (accessibility of units by drill rig) and number of major drainages present in the project area.
Eldorado NF: A risk assessment of the treated areas is based on the location of the area relative to water, the beneficial use of the water, and the potential for transport to these waters. Location of the unit relative to a stream or spring, the size of that stream or spring, and its topographic position influences the risk of chemical entering the water and the risk to beneficial uses of that water. Areas on a ridgetop have the lowest risk while those adjacent to larger flowing streams or above springs have the greatest risk. Class 4 streams are generally ephemeral draws and pose the smallest risk. Class 1, 2 and 3 streams are either perennial surface water streams or are intermittent. These streams have fairly large contributing areas so the risk of chemical introduction is greater although the higher water volumes tend to dilute any contamination below levels of concern. Treatment areas are grouped into increasing risk levels based on proximity to springs, lakes, reservoirs, ponds, meadows, perennial and higher classes of streams, lower to upper slopes, and the number of springs, meadows, streams within or adjacent to the unit (see table below). All of this is evaluated using GIS layers for the streams, springs, waterholes; water rights GIS coverage on private lands adjacent to FS lands on the ca.gov website; aerial photographs; stream classification layers; some field review and known TES species habitat and locations.

Risk Level	Risk Grouping
LEAST RISK	Group 1: No associated stream courses
	Group 2: Units are located beyond stream course buffer zones
	Group 3: Stream course associated. Upper-slopes/ ridgetop units
	Group 4: Stream course associated Mid to lower slopes units
	Group 5: Multiple stream courses and/ or a spring or meadow associated Upper-slopes/ ridgetop units
GREATEST RISK	Group 6: Multiple stream courses and/ or a spring or meadow associated Mid- to lower-slope units

For hexazinone, areas with greatest risk of the chemcial entering the groundwater are those with shallow water tables (either created by shallow soils, compacted ground or clay pans) and coarse textured soils which drain rapidly and are very permeable. For risk assessment, the soils and geology GIS layers are studied to determine if any of the above conditions exist especially geologic contact areas between two different bedrock types. Those areas where the groundwater has the ability to become surface flow or be discharged by wells are at greatest risk for off-site contamination. Therefore, previous groundwater monitoring had been conducted in areas where units lay upstream of perennial streams and non-domestic wells where evidence of shallow water tables exists. In cases where offsite impacts to domestic water quality could occur, the hexazinone levels in the groundwater (and surface water) were monitored.

Ice: Blank

Jones: Blank

Hairston-Strang: No current effectiveness monitoring known for forestry applications.

Lind: Only small areas treated on Forest, therefore will monitor all treatment areas for effectiveness.

36. **How is effectiveness determined** (water column sampling? bio-assessment? Other? Underline, circle, check or describe if other)?

Bakke: water column sampling

Danly: Mostly non-target vegetation effects.

DeGraff: Analysis of water drawn from monitoring well for concentration of hexazinone for comparison to State of California water quality goal for that chemical.

Eldorado NF: Water sampling (surface water grab samples) is conducted at the monitoring sites. Pre-sampling and lab analysis of results is conducted prior to herbicide application. Usually post-sampling is conducted after application and after/during the first rain event that produces runoff **within 90 days** of treatment. If no storm event has occurred, then no post sampling monitoring is conducted. Currently all water sampling is surface water sampling. Prior sampling conducted on the forest had included stream sediment sampling, soil sampling, and groundwater sampling (drilling wells). If there is no

detection based on the minimum detection limit for reporting, then it is assumed that all BMP measures were effective.

Ice: Blank

Jones: Blank

Hairston-Strang: Blank

Lind: Site visits checking for effects to both target and non-target species.

37. If buffers are established, how do you know that the width is adequate to protect water quality?

Bakke: Past experience; early projects had wide, conservative buffers. With experience in monitoring these initial wide buffers were reduced until detections were seen.

Danly: Buffers are expanded beyond what is required on the herbicide label and standard BLM protocols. This is precautionary and not based upon any "science" that I can determine. I guess we are trying to be cautious. At the local scale they can't be tested to detect movement of herbicides through the soil or in water as that is prohibitively expensive and time consuming. When the oversight and requirements to prove we are doing what we say we are doing take more time then the treatment, we may as well stop treating as it becomes prohibitively expensive. Weed control is one of the "white hats" and our efforts support management of specific weed problems at the local cooperative weed management area level. I would hate to see our efforts becoming so cumbersome that we could not participate.

DeGraff: Blank

Eldorado NF: If there are no positive results reported from the sampling, then it is assumed that the buffers were adequate to protect water quality.

If there is no detection then we assume that the buffers were adequate although the dilution effect of some of the larger streams may also be a factor. However, any positive results that are within the expected (predicted) rates may also indicate that these measures were also effective.

Ice: Blank

Jones: Blank

Hairston-Strang: Blank

Lind: The Forest does not test now, but has proposed to further investigate the effectiveness and practicality of conducting some level of water quality monitoring to detect levels of herbicides and possibly to establish the effectiveness of drift buffers.

38. **Describe specifics of the decision process used to locate the sampling site(s) and determine the frequency of sample collection** (attach a copy of the effectiveness (sampling) protocol).

Bakke: Draft R5 water monitoring protocol (I believe you already have).

Danly: Observation for non-target vegetation effects is done over the entire treatment area by visual observation.

DeGraff: Ideal sample locations were near the base of large treatment units where the monitoring well could be installed between unit and major stream with this site being co-located with surface water sample station in the same stream. Sampling was pre-treatment (baseline) and after first season of wet weather. Samples collected for several years due to lag in detectable quantities reaching groundwater (about 2 years).

Eldorado NF: See answer to question 35. In addition, sampling sites must be safe to get to and accessible within a normal time frame. When there are multiple sites to visit, it is difficult to spend more than ½ hour getting to it by foot which is important when

revisiting during a rain/snow event. The access cannot be through the unit that was treated in order to prevent contamination of the water by the sampler. The sampling site also needs to be on the stream where most of the water flows (such as a nick point) and preferably within a riffle. This riffle or a nearby one would be used to measure the amount of discharge. The stream preferably should be a smaller order perennial stream in order not to have a great dilution effect. Monitoring sites also attempt to capture not just one unit but also multiple treatment units that would drain into the same point. Frequency is based on pre-sampling, post-sampling following a rain event within 90 days of application, and any test results that are positive.

Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

39. **Is effectiveness determined differently for ground vs. aerial applications** (if yes, describe how)?

Bakke: No
Danly: No
DeGraff: No difference from a groundwater standpoint was noted.
Eldorado NF: N/A
Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: No, no aerial applications on Forest.

40. For any additional, future herbicide applications, do you repeat effectiveness monitoring through time (to track change in effectiveness)? If so, at what interval?

Bakke: Each new project has its own monitoring plan. To the extent that buffers have been narrowed with certain herbicides over time is an indication of tracking changes over time in effectiveness of buffers.

Danly: Post monitoring is done every year, so records are available for periodic review. We do review them to assure we are conducting an effective weed treatment program.

DeGraff: Monitoring should be carried out for each new project to ensure having data to demonstrate that water quality goal is being achieved. However, fewer monitoring stations may be acceptable per project.

Eldorado NF: Yes. For previous herbicide application using hexazinone, residue long-term monitoring was conducted frequently in the beginning (weekly) on many sites and tapered off to twice per year after spring run-off and after first fall rains for three sites (1992-2001). This is no longer done since all water samples were reported as no detection.

Monitoring is conducted on the same sites if the herbicide treatment is repeated next year. Both pre- and post-sampling following the protocol described is done.

The recent 2003 knapweed herbicide project treated individual and groups of noxious weeds along the gravel bars and banks of the South Fork Silver Creek. One of the sites chosen was directly below a gravel bar on the river to determine if the herbicide (Rodeo) would leach through the bar and into the surface water of the stream channel. Water monitoring was conducted as a pre-sample, then post-sample within one week of application, and post-sample again if there was a rain event to run-off.

Ice: Blank

Jones: Blank
Hairston-Strang: Blank
Lind: Blank

41. **What criteria are good indicators of effectiveness** (water quality standards? biological indices? other (specify)?)?

Bakke: Biological indices. Non-human biological indices that show levels of herbicide detections in water that represent a risk are much more useful than human water quality standards that are often much higher. Monitoring stream invertebrates has been proposed from time to time, but the natural variation in such populations would make this a difficult parameter.
Danly: Off target vegetation effects are the most easily observed and least costly to assess.
DeGraff: Blank
Eldorado NF: Detection of any chemical residue in the surface water would provide a good indicator of effectiveness in a timely manner although it may be difficult to determine what the problem is and where it came from (public or private lands) if the results are positive. This only monitors the water for the short term; long-term effects if any would be more difficult to determine.

Biological indices such as macroinvertebrate monitoring may be useful for general assessment of conditions but again is not a good indicator to pinpoint any problems (chemical or sediment?), where and what the cause is, and results are not reported in a timely manner.

Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

42. Which, if any, BMPs are more difficult to assess for effectiveness, and why?

Bakke: Blank
Danly: Any type of water quality sampling or soil sampling would be difficult at the local level. Mainly due to time constraints, workloads, and costs.
DeGraff: Prohibition in Record of Decision for R-5 Vegetation Management EIS against applying hexazinone to soils where it could enter groundwater. Requires professional judgment of geologist to determine whether treated units might impact wells on adjacent property. Only limited direct groundwater information available. Currently requiring identification of conditions that would indicate that groundwater could NOT reach well (distance, elevation difference, bedrock hydrology, etc.)
Eldorado NF: For herbicide application, the process involves multiple agencies and paperwork, recording, coordination, and jurisdiction at different levels. For example this would involve the Forest Service, private contractor, county agency, California Water Resources Board, EPA, laboratories, disposal sites, etc. Some of the BMPs are assessed through water monitoring, some through contract inspection, and others through post-monitoring field review. The documentation does not reside in one place or in one form. I would think that there is the possibility of water monitoring difficulties where private and public lands are both applying the same herbicides.
Ice: Most BMP assessments we are involved with utilize AgDISP or AgDRIFT modeling. We are hoping to conduct field trials of the use of half-booms, drift control adjuvents, and foliage interception the summer of 2004.
Jones: Blank

Hairston-Strang: Blank
Lind: Blank

Results: rates of BMP effectiveness

43. **If effectiveness monitoring shows that a planned BMP is not as effective as desired, is the ineffectiveness due to lack of implementation or actual ineffectiveness of the BMP? both? Explain.**

Bakke: The few instances where rates of contamination exceeded expected were the result of a lack of implementation of BMPs as planned (did not put buffer in place; did not observe the buffer; applied herbicide to shallow soils or rock adjacent to streams).
Danly: We have no reason to believe the expanded buffers to err on the side of caution are not effective.
DeGraff: BMP appears effective
Eldorado NF: The contractor representative and inspectors do the effectiveness monitoring. Any documentation or information is compiled in daily diaries. The problems that we've had are not necessarily with the BMP but more with the specific situation and the buffer and/or chemical that should be used. Our BMPs are very general and allow for site-specific molding. When results from our water monitoring indicate that there is a detectable level of herbicide present, then the problem may be in the lack of implementation due to difficult field conditions (spring or seep covered with vegetation), or lack of knowledge of how the chemical works differently in various soil or geological conditions (such as hexazinone and perched water tables).

All other BMPs are subject to the BMPEP for tabulating the results and for indicating the implementation and effectiveness ratings. For the herbicide BMPs there is no form to use for the Region BMPEP program. The vegetation manipulation (under which these BMPs fall) does not include them in form V.28. The form includes Practices 5.1, 5.2, 5.5, and 5.7 that deal with mechanical manipulation and the practices that relate to soil disturbance. Form V. 28 as all of our BMPs focus on hillslope monitoring, not necessarily a look at soil disturbance, but an increased potential for off-site transport if the hillslope indicators are observed. Any BMPEP form for herbicide monitoring wouldn't have been sensitive enough to pick up water column contamination.

Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Next year will be first year of implementation of BO; don't know yet.

44. **Cite examples of causes of ineffectiveness or ineffective situations** (e.g., specific direction is lacking on steps to be taken to determine the presence of surface water in small stream/springs with dense vegetative canopy).

Bakke: Blank
Danly: None. Properly trained employees implementing actions as they are trained is the best fix. Just because you have a step-by-step manual, does not mean you will do any better.
DeGraff: Blank
Eldorado NF: Herbicide presence due to applications on private lands is difficult to address. Although pre-samples are taken which theoretically would indicate if there is an outside source of contamination, if treatments occur during the same timeframe there is presently no way to isolate where the chemicals come from.

Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

45. **For any BMP(s) identified in #43, what corrective actions/revisions are needed to improve the BMP(s)?**

Bakke: Person(s) in field responsible for implementing BMPs during project must be familiar with NEPA document and planned BMPs, but also able to recognize site-specific conditions that may necessitate adding BMPs when none were planned.
Danly: Blank
DeGraff: Blank
Eldorado NF: Blank
Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

46. **Can you send me a copy of documentation of recent effectiveness monitoring results?**

Bakke: Reports from forests in R5, R5 summary report (all of which I think you already have)
Danly: Blank
DeGraff: Yes, reports available
Eldorado NF: Most copies sent. Will provide long-term hexazinone monitoring conducted on Eldorado N.F. and accompanying groundwater well results. Can provide copies of letters that addressed changed circumstances due to the landslides in the South Fork American River Highway 50 corridor upon request.
Ice: See http://www.ncasi.org/forestry/research/watershed/control.pdf
Jones: Blank
Hairston-Strang: Blank
Lind: None available at this time.

47. **If you know of other data on effectiveness rates (beyond your own), provide contact information for the keeper of the other data.**

Bakke: Blank
Danly: Blank
DeGraff: Blank
Eldorado NF: Blank
Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

48. **To meet water quality objectives, do additional BMPs need to be developed beyond what your institution normally implements** (if yes, for what reasons)?

Bakke: A need for agreed upon BMPs for noxious weed treatments within or immediately adjacent to streams, lakes, etc.
Danly: No
DeGraff: Can't see a need at this time
Eldorado NF: No
Ice: Blank
Jones: Blank
Hairston-Strang: Blank
Lind: Probably, to ensure that sublethal effects are not occurring to aquatic species. This is particularly true with spray adjuvants, the toxicity of which can be greater than the herbicide itself.

49. List any information or knowledge gaps re assessment of herbicide BMP effectiveness for aquatic resources.

Bakke: Blank
Danly: Rather than BMP effectiveness, the knowledge gaps are in how much of a risk these herbicides pose to aquatic resources at minute levels that may even reach live waters given label requirements let alone standard BMP implementation. The information used by NOAA fisheries to raise the "red flag" was data about DDT, an insecticide which was banned for a mirad of reasons. And some information on Atrazine, a herbicide which may be used by BLM but is not one of the main herbicide tools. We are working with expanded buffers, without knowing that there is even a risk for the most common herbicide tools.
DeGraff: Blank
Eldorado NF: Blank
Ice: We are looking to further test half booms, drift control adjuvents, foliage interception, and complex terrain effects. Runoff from storm events is also an important issue that we want to address.
Jones: Blank
Hairston-Strang: Blank
Lind: Adjuvant toxicities.

50. List any recommendations on other sources of information (people to interview, documents).

Bakke: Blank
Danly: Blank
DeGraff: Blank
Eldorado NF: Blank
Ice: Dr. Harold Thistle, USDA Forest Service (304-285-1574, hthistle@fs.fed.us), Dr. Tom Terry, Weyerhaeuser Company, Centralia, WA
Jones: Blank
Hairston-Strang: Blank
Lind: Blank

51. Any other comments that could help me better understand how you assess BMP implementation and (or) effectiveness?

Bakke: Blank
Danly: Blank

DeGraff: Blank
  Eldorado NF: Blank
  Ice: Blank
  Jones: Blank
  Hairston-Strang: Blank
  Lind: Blank

Assessment of Herbicide Best Management Practices:
BMP Effectiveness for Protecting Water Quality

Draft Questionnaire (7/1/03)

Purpose

Determine expert opinions on the implementation and effectiveness of herbicide Best Management Practices (BMPs) for protecting water quality

Introduction

- A federal interagency group is assessing the effectiveness of BMPs for protecting aquatic resources from herbicide treatments. The primary focus is on noxious weeds in forest and rangeland riparian zones but information from agriculture, reforestation and other herbicide uses is relevant also. This questionnaire is one vehicle for obtaining relevant information.
- If you are short on time, please focus on the Application Procedures and Effectiveness questions.
- Don't hesitate to contact me with any questions (Neil Berg, 510-559-6426, nberg@fs.fed.us).
- To expedite your completion of this questionnaire, if documentation exists that answers any of the questions, send me the documentation and state "see documentation" as the answer to the question.
- If you're really pressed for time and cannot complete the main questionnaire, there are seven questions at the end of the questionnaire that are critical ones. Please respond to those if nothing else.

For this questionnaire, BMPs are broadly defined as management directions, formal BMPs, product labels or organizational policy/practices/protocols (e.g., Forest Practice Rules).

Application Procedures

These "Application" questions should refer to the BMPs you address in the Implementation and Effectiveness questions below.

1. **Purpose of herbicide application? Noxious weed abatement? Reforestation? Other?** (underline, circle, check or describe if Other)?

   Burch: Blank
   Davis: Not an applicator
   Frazier: Reforestation
   Green: Reforestation
   Parker: Preface: In Region 3, we're just starting to conduct environmental analyses that include BMPs. The most recent is an "Environmental Assessment for Management of Noxious Weeds and Hazardous Vegetation on Public Roads on National Forest System Land in Arizona." My answers to the following questions will be based in the information in this EA.

   Control of noxious weeds and hazardous vegetation on public roads that pass through National Forest System lands in Arizona.

2. **What chemical(s) (brand name(s)) is used?**

Burch: Blank
Davis: NA
Frazier: Hexazinone, triclopyr, glyphosate
Green: Blank
Parker: 2,4-D, Telar [chlorsulfuron], Transline [clopyralid], Dicamba, Vista [fluroxypyr], Roundup [glyphosate] and Rodeo [glyphosate], Plateau [imazapic], Arsenal [imazapyr], Gallery [isoxaben], Escort [metsulfuron methyl], Pendulum [pendimethalin], Tordon 22K [picloram], Poast [sethoxydim], Oust [sulfometuron methyl], Spike [tebuthiuron], and Garlon 3A and Garlon 4 [triclopyr].

3. **Is the herbicide(s) applied by backpack, tractor/ATV, helicopter, fixed wing aircraft, other?** (underline, circle, check or describe if other)

Burch: Blank
Davis: NA
Frazier: Backpack and helicopter
Green: Blank
Parker: Mostly large truck sprayers, but some minor backpack application. Aerial application has not be considered.

4. **Is the chemical applied as a pellet, liquid, other?** (underline, circle, check or describe if other)

Burch: Blank
Davis: NA
Frazier: Pellet and liquid (hexazinone); liquid for glyphosate and triclopyr
Green: Blank
Parker: Mostly liquid, but a small amount of tebuthiuron pellet application.

5. **List any aspects of the application procedure (e.g., nozzle type and orientation) relevant to assessing BMP implementation and/or effectiveness.**

Burch: Blank
Davis: NA
Frazier: Blank
Green: Blank
Parker: (1) Use the lowest pressure, largest droplet size, and largest volume of water permitted by the label to obtain adequate treatment success. (2) Use the lowest spray boom and release height possible consistent with operator safety. (3) Only those herbicides labeled for use to the edge of bodies of water or with aquatic labeling shall be used within buffer zones and aquatic situations. (4) Buffer zone near bodies of water is at least 30 on relatively level ground. (5) Clopyralid, dicamba, picloram, and the sulfonlurea products not be used where the water table is within 6 feet of the surface.

If you (or your organization) do aquatic BMP implementation monitoring for herbicides, continue with the Implementation section. If you do aquatic BMP effectiveness monitoring for herbicides, but not implementation monitoring, go to the Effectiveness section. If you do both, continue with the Implementation section.

Implementation

For purposes of this questionnaire, define implementation as doing what we said we'd do to protect water quality.

6. **What BMPs do you implement? Buffers? Prohibition of chemical directly onto surface water? Weather criteria? Other?** (describe with specifics)

Burch: Landscape features
Davis: Blank
Frazier: USDA FS BMPs 5-8 to 5-13 [see Appendix XX, California FS]
Green: Avoid application adjacent to stream (20-100' min & max).
Parker: Preface: Implementation will be under the direction of certified applicators in the Arizona Department of Transportation (ADOT), and they will accept the responsibility to comply with mitigations and BMPs listed in the EA.
See items under question 5.

7. **How do you determine what BMPs to implement?**

Burch: Blank
Davis: Blank
Frazier: N/A – they're all used in the NEPA planning document and administered during the layout and contract
Green: Depends on whether streams are perennial or intermittent as to width of SMZs.
Parker: Developed jointly by FS and ADOT specialists, and reviewed by the public.

8. **Are there any weaknesses in the determination process** (if yes, describe)?

Burch: We typically see little or nothing on environmental toxicity information such as impacts to non-target species, environmental persistence, or timing related to species of concern (particularly important if application is to occur during sensitive periods such as nesting.
Davis: Blank
Frazier: N/A
Green: Use of topo maps and county soil survey maps. Topos don't show intermittents as well as NRCS. Not all counties have published NRCS maps.
Parker: No. The process exceeds the requirements for applications outside of National Forest System lands.

9. **How do you determine what herbicide treatments/sites/projects to assess for implementation** (e.g., review of environmental documents to determine where/which BMPs should be applied--describe with specifics)?

Burch: Blank
Davis: Blank
Frazier: Blank

Green: Soil, vegetation to be control. Try to assess 10% of silviculturally treated sites. Get a mix of reforestation.
Parker: Part of the environmental analysis process.

10. **Is there a statistical component to the selection process** (if yes, describe)?

Burch: Blank
Davis: Blank
Frazier: No – all projects are monitored for implementation of BMP 5-12 [Streamside wet area protection during spraying], the main BMP that get applied to the ground.
Green: yes
Parker: No

11. **Is there a QA/QC component to the selection process** (if yes, describe)?

Burch: Blank
Davis: Blank
Frazier: N/A
Green: No
Parker: Yes. Under a Memorandum of Understanding, the FS, Federal Highway Administration, and ADOT have agreed to meet annually and develop an annual operating plan. The plan will include: Assessment of previous year's actions, locations of planned treatments, methods of application, additional mitigation and other constraints, and reporting of herbicide use. ADOT agrees to comply with all requirements in the annual plan. The weakness is that FS personnel will not check compliance during operational treatments.

12. **Are there weaknesses in the site selection process** (if yes, describe)?

Burch: Blank
Davis: Blank
Frazier: N/A
Green: yes as there are in any sample
Parker: Public roads are not immediately adjacent to bodies of water, and the risk of water contamination from applications is low.

13. **Describe the implementation monitoring process for each BMP (or group of BMPs). How is it done?**

Burch: Blank
Davis: Blank
Frazier: Blank
Green: See Southern Group of State Foresters monitoring protocol
Parker: See 11 above.

Aerial applications (#14-20):

14. **Buffer designation and width** (e.g., spray cards at edge of buffer, other)?

Burch: Blank
Davis: Blank

Frazier: Visual observation
Green: Blank
Parker: Not an option.

15. **Flight path direction, height** (e.g., visual observation, other)?

Burch: Blank
Davis: Blank
Frazier: Visual observation
Green: Blank
Parker: Blank

16. **Nozzle type/orientation** (e.g., direct inspection, other)?

Burch: Blank
Davis: Blank
Frazier: Inspection by COR or contract inspectors
Green: Blank
Parker: Blank

17. **Location of surface water** (e.g., aerial inspection, walking stream, other)?

Burch: Blank
Davis: Blank
Frazier: Buffers are designated on the ground as soon as possible before application by project managers and then checked by the pilot prior to application
Green: Blank
Parker: Blank

18. **Weather conditions** (on-site gauging of relative humidity, wind speed and direction, other)?

Burch: Blank
Davis: Blank
Frazier: Measured on-site by contract inspectors
Green: Blank
Parker: Blank

19. **Storage, handling, transport … Etc.**

Burch: Blank
Davis: Blank
Frazier: Inspected by contract inspectors
Green: Blank
Parker: Blank

20. **Other aerial application BMPs**

Burch: Blank
Davis: Blank
Frazier: Blank

Green: Blank
Parker: Blank

Ground applications (#21-25):

21. **Buffer width** (e.g., spray cards at edge of buffer, other)?

Burch: Blank
Davis: Blank
Frazier: Same as aerial application
Green: Blank
Parker: Buffer width is at least 30 feet on level ground, although most public roadways easements are further than 30 feet from bodies of water.

22. **Weather conditions** (on-site gauging of relative humidity, wind speed and direction, other)?

Burch: Blank
Davis: Blank
Frazier: Same as aerial application
Green: Blank
Parker: Rely on label requirements.

23. Application rate.

Burch: Blank
Davis: Blank
Frazier: Same as aerial application
Green: Blank
Parker: Rely on label requirements.

24. Storage, handling, transport ... Etc.

Burch: Blank
Davis: Blank
Frazier: Same as aerial application
Green: Blank
Parker: Rely on label requirements.

25. Other ground application BMPs.

Burch: Blank
Davis: Blank
Frazier: Same as aerial application
Green: Blank
Parker: Environmental document

26. **Describe any weaknesses or difficulties in assessing the implementation of any particular practices** (e.g., identifying presence of surface water in heavily vegetated channels).

Burch: Typically no sampling is proposed or conducted to determine actual application rates and little information is provided on the toxicity, environmental fate, etc. of the surfactant(s). Little information is provided on the health of riparian vegetation and related communities. At a minimum, we believe that applications should be conducted according to Department of Agriculture procedures/limits for the appropriate chemicals.

Davis: Blank
Frazier: Blank
Green: Blank
Parker: Blank

27. Results: rate of implementation for herbicide practices.

Parker: Decision has not been made under environmental analysis process.

28. **Results: How are implementation rates specified** (what metric(s) are used—e.g., percent implemented properly)?

Burch: Blank
Davis: Blank
Frazier: Big Note here: there are no forms for documenting herbicide application implementation in the R5 [USDA Forest Service Pacific Southwest Region] BMPEP [Best Management Practices Evaluation Program]. When the BMPEP was developed it was recognized that herbicide application was an intensive "specialty" type of monitoring that engendered in-stream effectiveness monitoring and contract inspection by FS inspectors (daily logs) to assess implementation. Question: should BMPEP develop forms for implementation compliance?
Green: Blank
Parker: Blank

29. Results: Can you send me copy of documentation of recent results?

Burch: Blank
Davis: Blank
Frazier: Blank
Green: Blank
Parker: Blank

30. Results: Do you know of other data on implementation rates (beyond your own)?

Burch: Blank
Davis: Blank
Frazier: Blank
Green: Blank
Parker: Blank

31. List any information or knowledge gaps re assessment of herbicide BMP implementation for aquatic resources.

Burch: Blank
Davis: Blank

Frazier: See #28.
Green: Blank
Parker: Blank

Effectiveness

For purposes of this questionnaire, define effectiveness as how well water quality is protected by implementing the BMP(s).

32. Describe how sites are selected for effectiveness monitoring (including statistical approach if used).

Burch: Blank
Davis: Blank
Frazier: Varies by project. We've used a multiple scale nested watershed approach and basically censused 6th and 7th field HUCs to this point. We may do less in the future with knowledge gained over many years of monitoring. If so, the basis will be (1) beneficial uses most at risk and (2) random within the stratification of item 1.
Green: Blank
Parker: No implementation to date.

33. **Is effectiveness determined by water column sampling, bioassessment, other?** (underline, circle, check or describe if other)

Burch: Blank
Davis: Blank
Frazier: Water column since that is most directly tied to state water quality objectives
Green: Blank
Parker: Blank

34. Describe specifics of the assessment procedure (e.g., decision process used to locate site and determine frequency of sample collection).

Burch: Blank
Davis: Blank
Frazier: Blank
Green: Blank
Parker: Blank

35. Can you send me a copy of the effectiveness (sampling) protocol?

Burch: Blank
Davis: Blank
Frazier: Will send
Green: Blank
Parker: Blank

36. **Is effectiveness determined differently for ground vs. aerial applications** (if yes, describe how)?

Burch: Blank
Davis: Blank
Frazier: No – it's effectiveness relative to water quality objectives so the method of application doesn't matter.
Green: Blank
Parker: Blank

37. Is the assessment procedure repeated through time (to track change in effectiveness)? If so, at what interval?

Burch: Blank
Davis: Blank
Frazier: I don't think I understand the question
Green: Blank
Parker: Blank

38. **What criteria are good indicators of effectiveness** (water quality standards? biological indices? other?)

Burch: Blank
Davis: Blank
Frazier: Water quality objectives – though some are not directly applicable to us. Biological indices are OK, too, but less quantitative relative to water quality objectives.
Green: Blank
Parker: Blank

39. Which, if any, practices are more difficult to assess for effectiveness, and why)?

Burch: Blank
Davis: Blank
Frazier: I don't think I understand the question – what does practices mean here?
Green: Blank
Parker: Blank

40. Under what conditions (e.g., aerial vs. ground application, topography, weather) are the BMPs not/less effective?

Burch: Blank
Davis: Blank
Frazier: If buffers aren't fully observed it is more likely to entrain herbicide in water. We have found that aerial has more risk in general but ground application can have problems, too.
Green: Blank
Parker: Blank

41. What (if any) specific BMPs don't work/need improvement?

Burch: Blank
Davis: Blank
Frazier: 5-12 [Streamside wet area protection during pesticide spraying] and 5-13 [Controlling pesticide drift during spray application] are the field implementation

BMP's and need the most care in planning and implementation to gain good effectiveness.

Green: Blank
Parker: Blank

42. What corrective actions/revisions to BMPs are needed?

Burch: Blank
Davis: Blank
Frazier: None – but implementation needs to be carefully done. The right practices are covered by the existing BMP's.
Green: Blank
Parker: Blank

43. Can you send me copy of documentation of recent results?

Burch: Blank
Davis: Blank
Frazier: It's in the report I'm sending
Green: Blank
Parker: Blank

44. Do you know of other data on effectiveness rates (beyond your own)?

Burch: Blank
Davis: Blank
Frazier: See Bakke's R5 Report dated 2001 for a Regional result summary
Green: Blank
Parker: Blank

45. **Cite examples of causes of ineffectiveness or ineffective situations** (e.g., specific direction is lacking on steps to be taken to determine the presence of surface water in small stream/springs with dense vegetative canopy).

Burch: Blank
Davis: Blank
Frazier: It's in the report I'm sending – see the last appendix.
Green: Blank
Parker: Blank

46. **To meet water quality objectives, do additional practices need to be developed** (if yes, for what reasons)?

Burch: Blank
Davis: Blank
Frazier: No – but existing ones need to be implemented well. Proper buffer zones are the principal BMP for getting good results, assuming the contractor doesn't violate them.
Green: Blank
Parker: Blank

47. List any information or knowledge gaps re assessment of herbicide BMP effectiveness for aquatic resources.

Burch: Blank
Davis: Blank
Frazier: ??
Green: Blank
Parker: Blank

48. List any recommendations on other sources of information (people to interview, documents).

Burch: Blank
Davis: Blank
Frazier: Bakke's Report
Green: Blank
Parker: Blank

49. Any other comments that could help me better understand how you assess BMP implementation and (or) effectiveness?

Burch: Blank
Davis: Blank
Frazier: Blank
Green: Blank
Parker: Blank

Short Version 7/1

A. Does your organization have herbicide BMPs in place for protecting water quality (yes/no)?

Burch: No
Davis: We often suggest them as RPA/RPMs or as conditions under our consultation process.
Green: Yes

B. What type of herbicide application is used (air/ground)?

Burch: Blank
Davis: Blank
Green: both

C. Does your organization monitor the aquatic effectiveness of the BMPs (yes/no)?

Burch: No. We require monitoring by other agencies through consultation but little effort is expended in enforcement, so monitoring may or may not be conducted.
Davis: Can suggest the action agency do so
Green: no

D. If so, how?

Burch: Blank
Davis: Blank
Green: Blank

E. If so, what are the results of the monitoring (send documentation or describe)?

Burch: Blank
Davis: Blank
Green: Blank

F. Do you believe the herbicide BMPs are effective for protecting water quality?

Burch: This is unknown.
Davis: variable
Green: yes, when BMPs & label are followed

G. If not, why not?

Burch: We have yet to receive adequate, complete post-application reports from consulting agencies.
Davis: Depends on many site-specific factors including: type of chemical, application method, rate, soil type, slope organic content of soil, rain-fall, timing, etc. in some cases they may be effective & thus protective.
Green: Blank

Appendix E. Environmental Fate of Selected Herbicides

Introduction

This section summarizes readily available information on the environmental fate of nine herbicides commonly used by federal land management agencies for noxious weed control or reforestation purposes. These summaries focus on soil and water effects under the presumption of conservative herbicide treatment procedures in forested environments, specifically ground application and implementation of all relevant BMPs. Potential biological ramifications of herbicide use are not included. These summaries are taken from USDA Forest Service 2003a.

Results of simulation modeling of pond water concentrations of several of the herbicides are included. The model used is GLEAMS (Groundwater Loading Effects of Agricultural Management Systems), a root zone model incorporating various types of soils under different meteorological and hydro-geological conditions (SERA 1999:3-14). GLEAMS is not site-specific. It provides generic estimates of chemical concentrations by simulating herbicide application to a 10-acre right-of-way 50 feet wide and 8,712 feet long, with the simulated, 3.2 feet deep pond running along the length of the right-of-way. The 10-acre plot slopes 10 or 20 percent toward the water, and no buffer separates the application zone from the water body (SERA 1999:3-15).

Clopyralid

Overview

Persistence of clopyralid in soil is variable with documented half-lives ranging from 10 days to 10 months depending on soil type and climate. Although clopyralid does not bind readily to soil, it dissipates rapidly in some common soil conditions, and typically is not expected to leach appreciably in non-sandy, low-to-moderate rainfall conditions. No known metabolites of clopyralid were identified. The very limited field monitoring of ground-applied clopyralid in forest streams documented undetectable concentrations. Foliar application is the primary mode of treatment.

Information Sources

A number of secondary sources were reviewed in the summary below. One annual report on the transport and dissipation of clopyralid, and other herbicides, used to control kudzu, is reviewed. A US EPA Reregistration Eligibility Decision is not available for clopyralid.

Disposition in Soil

Microbes are the main agent of degradation for clopyralid in soil (Pik et al. 1977 and Smith and Aubin 1989, cited in Bush 2001:7, State of California 2002, US Dept. Energy 1999, Information Ventures, Inc. 1995). Dow AgroSciences (1998) pointed out that environmental factors, including soil moisture and temperature, that affect microbial activity, also influence the degradation rate of clopyralid and that "... clopyralid degradation is considerably limited under cold, dry or anaerobic soil conditions, and most rapid under warm, moist aerobic soil conditions". SERA (1999:4-18) stated: "... clopyralid will be rapidly degraded except in arid soils with low microbial populations."

Metabolites of clopyralid do not appear to be common. SERA (1999:4-11, App. 6-1) cited crop rotation and laboratory studies, neither of which identified soil metabolites (Yackovich et al. 1993, Baloch and Grant (1991a). SERA (1999:3-5, citing Bosch 1991) also identified a study of mammal metabolism of clopyralid that implied "no evidence for the existence of significant metabolites."

Persistence

Clopyralid in soils is described variably as ranging from "persistent" to "non persistent". Again, site-specific environmental conditions probably drive these determinations. Over a three-year period, clopyralid was not persistent in a Georgia lysimeter study (Bush 2001). "... following a 4 ounce acid equivalent/acre treatment, which is the highest labeled application rate, of clopyralid to bare ground in Fresno, California, 99% of the residual herbicide was found in the top 18 inches of the soil 4 months after treatment; this was measured with an 80% normal rainfall. In the same study, clopyralid degraded to 1% of the total applied herbicide after 3 months" (WeedRIC undated). US Dept. Energy (1999) described clopyralid as " ... moderately persistent in the plant [sic] and soils." In a differing opinion, Cox (1998:17) cited several sources (e.g., Pik et al. 1977, Bovey and Richardson 1991, Tanphiphat and Burrill 1987) in describing clopyralid as persisting in soil from 2 to 14 months after application, depending upon soil type, climate and other factors. Similar to other herbicides, clopyralid persistence is longer in anaerobic conditions with low microorganism content (Information Ventures, Inc. 1995); in laboratory tests "[D]egradation over 300 days was not considerable enough to calculate in the Commerce loam waterlogged [i.e. anaerobic] soil ... " (Dow AgroSciences 1998).

Clopyralid half-lives in soil also vary, depending upon environmental conditions, although many sources cite half-lives ranging from 10 days to 3 months:

- "12-70 days, depending on the soil type and climate" (WeedRIC undated)
- 28, 43 and 11 days, under average, dryer and moister conditions for aerobic soils in the United States (Dow AgroSciences 1998)
- 10 days on highly permeable loamy fine sand soil in a high rainfall region (Petty and Knuteson 1991, cited in SERA 1999:App. 6-1)
- 57 and 161 days in cultivated soil and high humic acid soil respectively (Schutz et al. 1996, cited in SERA 1999:App. 6-1)
- 10-47 days depending on temperature and soil composition (Smith and Aubin 1989, cited in SERA 1999: 4-12)

Other listings of clopyralid half-lives are "up to 11 months" (Cox 1998:17, citing US EPA 1992), 40 days (US Dept. Energy 1999), 12-90 days (various sources, cited by delaFuente undated), and 15 to 287 days (Information Ventures, Inc. 1995).

Mobility and Leaching

Although the physical properties of clopyralid (e.g., acidity, water solubility and stability to hydrolysis and photolysis (Dow AgroSciences 1998)) suggest it is mobile in soil and has an appreciable likelihood for leaching, the rapid rate of clopyralid degradation in field conditions reduces the potential for considerable contamination of deep ground water in non-porous soils. Many sources (e.g., Bush 2001, numerous references cited in SERA 1999:4-4) acknowledge that clopyralid does not bind readily to soil. Others go further in asserting mobility and leaching of clopyralid:

- " ... clopyralid is quite water soluble and mobile in soil ... " (delaFuente undated)

- "There is a high potential for clopyralid to leach into groundwater when applied over shallow aquifers or to soils having high permeability" (US Dept. Energy 1999)
- "... Clopyralid [is] 'very soluble' in water and 'very mobile' in soil and ... 'has the potential to leach to ground water and/or contaminate surface water'" (Cox 1998: 17, citing US EPA 1997)
- "The mobility of clopyralid in soil is considered moderate, so some leaching can occur" (WeedRIC undated)

Other sources cite lysimeter studies and modeling which argue for restricted leaching:

- "... field lysimeter studies ... suggest that the rapid degradation of clopyralid in soil is the predominant factor in the functionally low rate of both leaching and runoff" (Baloch-Haq et al. 1993 and Bergstrom et al. 1991, cited in SERA 1999: 4-12)
- "... the behavior of the compound [clopyralid] under field conditions demonstrates fairly rapid degradation and limited downward movement" (Dow AgroSciences 1998)
- "A number of field lysimeter studies and one long-term field study indicate that leaching and subsequent contamination of ground water are not likely to be substantial" (SERA 1999: xv)
- "... Rubin (1999a, cited in Bush 2001:7) concluded that the potential for clopyralid to leach is functionally reduced by its relatively rapid degradation in the soil."
- "... under actual field environmental conditions" documented in European lysimeter studies in 1991 and 1994, Dow AgroSciences (1998) concluded that "... clopyralid rapidly dissipates ... [and] ... the very low levels observed in leachate demonstrate that there is very little potential for clopyralid to leach through soil and contaminate ground water."
- Bush (2001) monitored four herbicides in lysimeters concurrently and determined the "... relative potentials of herbicides to move into shallow groundwater [was]: picloram > metsulfuron methyl > clopyralid > triclopyr"
- PRZM modeling of five highly permeable soils for clopyralid dissipation and movement in Texas rangeland conditions "... demonstrated that maximum depth of residues was 18-inches, 73 days after application in a highly permeable fine sand, with no residue detections through the entire profile of all soils by 6 months after application" (Dow AgroSciences 1998)
- "In our study, clopyralid ... did not move laterally, ..." (Bush 2001:7)

In summary, the potential for clopyralid leaching is best considered site-specifically. For instance sandy soil, sinkholes or severely fractured surfaces, with high rainfall, a shallow water table and sparse microbial population are most likely to experience leaching (SERA 1999) and groundwater contamination (Information Ventures, Inc. 1995).

Soil Water Concentrations

The relatively few documented soil water concentrations of clopyralid vary and although both field and modeling suggest soil water concentrations greater than 100 parts per billion (ppb) are possible, the relevancy of these results to ground-applied clopyralid in forest settings is incompletely known. In a Georgia field study Bush (2001) measured clopyralid levels of 0.42-2.84 ppb in 12 of 102 deep (84-109 cm) lysimeter samples collected over a three-year period from July 1997 to August 2000. "Across all [field study] blocks, clopyralid was detected at levels of 0.5-127 ppb in only 18 of the 92 shallow leachate samples ..." (Bush 2001:8). In a field lysimeter study incorporating irrigation plus natural rainfall and designed to document a "worst

case" scenario for clopyralid mobility Elliott et al. (1998, cited in SERA 1999:4-12) observed a maximum soil water concentration of 187.3 mg/l over a 21-day post-application period.

Disposition in Water

Persistence

Depending upon soil and geo-climatic conditions, clopyralid can persist in aerobic surface waters potentially over 30 days. Clopyralid is readily water-soluble. "It is not susceptible to breakdown by sunlight and hydrolysis and has low volatility" (State of California 2002). Half-lives of clopyralid in water are listed as:

- "greater than 30 days" (State of California 2002)
- 9 days average field half-life in a southern Ontario pond (Dow AgroSciences 1998)
- 22 days in a colder climate, Alberta (Dow AgroSciences 1998)

The relevancy of results from pond studies is incompletely known relative to stream environments that are probably more common in forest and rangelands. Elevated dilution and mixing in streams compared to lakes would be expected to reduce residence times in streams compared to lakes.

Clopyralid is described as being extremely stable in anaerobic sediments, with no significant decay noted over a one year period" (Hawes and Erhardt-Zabik 1995, cited in SERA 1999:3-13).

Surface Water Concentrations

Insufficient information is available to generalize about surface water concentrations of clopyralid from forestry applications. The one known field monitoring study of ground-applied clopyralid in forest streams documented no detectable concentrations of the chemical (App. B). These preliminary results from the Eldorado National Forest in California were from two sampling sites after the first major post-application storm (Carroll 2002). The USGS National Water Quality Assessment Program (NAWQA) databases (http://ca.water.usgs.gov/pnsp) entitled *Pesticides in Streams, 1992-2001* & *Pesticides in Ground Water, 1992-2001* list "frequency of detection" results for undeveloped land uses from four sites (19 stream samples and 46 well samples) as zero for both the stream and well samples. The application type (e.g., aerial, ground) and buffers use or other BMPs are not stated in the NAWQA documentation.

In an Australian study, Leitch and Fagg (1985, cited in SERA 1999:3-14) measured a maximum post-initial storm concentration of clopyralid as 0.017 mg/l. The Australian samples were collected 0.5 km (1,640 feet) downstream from the application location and the clopyralid was aerially applied. Aerial application typically is less controllable than ground application and surface water concentrations from aerial application are often higher than concentrations from ground application. In addition, the Australian study use an application rate (1.9 lb acid equivalent/acre) that is about four times the rate typically used in Forest Service applications.

Runoff and percolation coupled with lateral sub-surface flow are two major mechanisms of entry for water into stream channels. SERA (1999:4-18) noted, "... runoff ... does not appear to be a major concern with clopyralid. Rains are most likely to cause clopyralid to leach into the soil column rather than wash-off. ... once in the soil column, clopyralid will be rapidly degraded except in arid soils with low microbial populations."

Glyphosate

Overview

Extensive water quality monitoring in forest streams suggests that ground-applied glyphosate would be marginally detectable in adequately buffered streams. Glyphosate is moderately persistent in soil with the preponderance of documented half-lives ranging from 25 days to 4 months. A major metabolite of glyphosate, AMPA, behaves in soil and water similarly to glyphosate. Glyphosate adsorbs strongly to most soils, is only slightly mobile, and typically hasn't been shown to leach below 12 inches soil depth. Foliar application is the primary mode of treatment.

Information Sources

A variety of secondary information sources form the primary basis for this summary. Several older primary sources offer field monitoring data and information on degradation of glyphosate in the aquatic environment. Although a US EPA Reregistration Eligibility Decision exists for glyphosate, because of its relatively early publication date, 1993, it is supplemented by the other information sources. Results of extensive field monitoring of glyphosate in forest streams are included.

Disposition in Soil

Glyphosate resists chemical degradation in the soil environment (Schuette 1998) and breaks down via soil microbial action to aminomethyl phosphonic acid (AMPA) that in turn degrades to carbon dioxide (US EPA 1993b: 4, Information Ventures, Inc. 1995, Schuette 1998).

Persistence

Most sources describe glyphosate as moderately or relatively persistent in soils (US EPA 1993a:54, Extoxnet 1996, Schuette 1998) although in a differing opinion Cox (1998:11 citing US EPA 1993) described glyphosate as "extremely persistent under typical application conditions." Breakdown of AMPA is generally slower than glyphosate (Schuette 1998, US EPA 1993a:37).

Soil half-lives vary for glyphosate, depending somewhat on soil and climatic conditions. Identified half-lives include:

- 3-130 days (Information Ventures, Inc. 1995)
- 20-40 days (Weber 1991, cited in SERA 1996:2-2)
- < 60 days (average) (WSSA 1989, cited in SERA 1996:2-2)
- 45-60 days (Feng and Thompson 1990, cited in SERA 1996:2-2)
- 29-40 days (Newton et al. 1984, cited in SERA 1996:2-2)

Other sources provide detail in half-life assessments:

- 1.85 to 2.06 days in aerobic soils, specifically Kickapoo sandy loam and Dupo silt loam (US EPA 1993a: 31)
- median 13.9 days, ranging from 2.6 days (Texas) to 140.6 days (Iowa), with "...glyphosate residues in the field ... somewhat more persistent in cooler climates as opposed to milder ones (Georgia, California ...)" (US EPA 1993a:31)

- 96.4 days as average of five samples in different aerobic soils (Schuette 1998)
- 44 days as average for field dissipation of samples from two different soil types (Schuette 1998)
- 24 days in sandy soil (Roy et al. 1989, cited in Schuette 1998)
- 35 to 158 days in forestry dissipation studies in Michigan, Oregon and Georgia (US EPA 1993a: 35)

Half-lives for AMPA are given as:

- 240 days (median from 8 sites in a terrestrial field dissipation study), with a range of 119 (Ohio) to 958 (California) (US EPA 1993a: 33)
- 71 to 165 days, in forestry dissipation studies in Michigan, Oregon and Georgia (US EPA 1993a: 35)
- 118 days, in a forestry dissipation study at a high rainfall site (Horner 1990, cited in Schuette 1998)

Depending upon soil and climatic conditions, glyphosate can persist for months at lower concentrations in soil. Feng and Thompson (1990) detected 6-18% of the initially apply glyphosate after 360 days at 30 cm (1 foot) soil depth. At some forestry sites in Finland and Sweden, glyphosate was detectable for 259 and 296 days, and one to three years respectively (Torstensson and Stark 1979, Torstensson et al. 1989, both cited in Cox 1998:11).

Mobility and Leaching

Glyphosate adsorbs strongly to most soils (SERA 1996:xii), even those with lower organic and clay content (Extoxnet 1996), and glyphosate "...was shown to remain predominantly in the 0-6" soil layer ..." (US EPA 1993a: 32). Other sources described glyphosate as "very slightly mobile" (Linders et al. 1994, cited in Schuette 1998), with "low mobility" (WHO 1998), "only a slight tendency to leach in soil" (Schuette 1998), and "... tightly complexed [bound] by most soils, [and] ... in most soils ... essentially immobile" (Franz et al. 1997, cited in Cox 1998:11).

Because of the low probability of movement, ground and surface water contamination is unlikely. In support of the re-registration of glyphosate, no confirmed evidence of movement of glyphosate below 12 inches soil depth was identified in interim results from a multi-site terrestrial field dissipation study (US EPA 1993a: 32-33). Laboratory studies supported this finding (US EPA 1993a: 32, 37). Information Ventures, Inc. (1995) noted that the potential for glyphosate leaching is low. In a differing opinion, Cox (1998) pointed out that under certain conditions, glyphosate can desorb, and that glyphosate has been described as being "extensively mobile ..." (Cox 1998:11, citing Piccolo et al. 1994). Extoxnet (1996, citing Edwards et al. 1991 and Wauchope et al. 1992) summarized the prevailing opinion: "Thus, even though it is highly soluble in water, field and laboratory studies show it does not leach appreciably, and has low potential for runoff (except as adsorbed to colloidal matter)".

AMPA also is not likely to move to ground water due to it's strong adsorptive characteristics (US EPA 1993b: 4). Results of a terrestrial field dissipation study showed that AMPA remained "... predominantly in the 0-6" soil layer through the duration of the study at all field sites" (US EPA 1993a: 32).

Disposition in Water

Persistence

Degradation of glyphosate is probably slower in water than soil because the opportunity for microbial break down, a prime mode of degradation (Extoxnet 1996, Zaranyika and Nyandoro 1993), is less in water (Ghassemi et al. 1981, cited in Schuette 1998) and because photochemical degradation is minimal (WHO 1998). US EPA (1993b: 4) concluded "[I]f glyphosate reached surface water, it would not be broken down readily by water or sunlight." And Kirkwood's Manitoba Canada studies (1979), cited in Schuette 1998) suggested that glyphosate loss from water is through sediment adsorption.

Depending upon the type of aquatic environment, half-lives of glyphosate in water vary from less than 2 days to over 2 months. Recorded aquatic half-lives include:

- 50-70 days (SERA 1996:2-2, citing US EPA 1992a)
- 35-63 days (Information Ventures, Inc. 1995)
- 1.5 to 3.5 days as the first order half-life in Canadian boreal forest ponds Goldsborough and Beck (1989)
- 8.1 days in anaerobic silty clay loam sediment (US EPA 1993a)
- 7 days in flooded aerobic clay loam sediment incubated in the dark at 25C for 30 days (US EPA 1993a)

In addition, Schuette (1998) cited several sources in summarizing that "[I]n streams, [glyphosate] residue was undetectable in 3-14 days."

Surface Water Concentrations

Glyphosate has not been recorded in detectable quantities in known monitoring of buffered forest streams in northern and central California, except in accidental application directly onto surface waters. Although "... glyphosate does have the potential to contaminate surface waters due to its aquatic use patterns and through erosion, as it adsorbs to soil particles suspended in runoff" (US EPA 1993b), glyphosate degrades relatively quickly by microbial activity, and glyphosate concentrations are further lowered as it binds to suspended soil particles (SERA 1996, citing numerous sources). When mitigation controls are applied (e.g., sufficiently wide buffers and ground application—Gluns 1989) glyphosate is typically non-detectable. From 103 samples collected between 1991 and 1999 from various national forests in the Sierra Nevada of California, Bakke (2001) concluded that with buffers and ground application, none of the samples had detectable concentrations of glyphosate (Appendix D). However, one other sample, from the only noxious weed project in the dataset, detected glyphosate after application within the riparian zone (Bakke 2001). In a similar study in the north coast of California, of 108 stream samples collected after ground and aerial application, none of had detectable concentrations of glyphosate (Jones and Wofford 1999, Jones et al. 2000).

In stating "[T]here is no information suggesting that glyphosate applications will result in significant levels of the compound in water over prolonged periods of time", SERA (1996:3-27 to 3-28) noted field evidence reported by Reynolds et al. (1993) of glyphosate levels in stream water ranging from non-detectable (<0.1 μg/l) to a trace (<1.0 μg /l) following storm events that occurred 20 - 150 days after application.

There are no known monitoring or modeling studies of the disposition of AMPA in stream water.

Indirect Effects on Stream Chemistry

Glyphosate application has been associated with concentration increases of some chemicals in streams and decreases of others. In a study of two watersheds in southwestern British Columbia, Feller (1989) identified no significant change in stream water chemistry after glyphosate had reduced vegetation cover by 4%. However, when cover was reduced by 43% considerable changes in stream chemistry were identified that lasted at least five years. Potassium, magnesium, and pH showed the most prolonged increases, and nitrate exhibited the greatest proportional increase. Sulfate and SiO2 concentrations decreased following herbicide application. Fluxes in stream water chemistry were less considerable and no decreases were observed.

Hexazinone

Overview

Extensive water quality monitoring in forest streams suggests that detectable concentrations of hexazinone are likely in some situations. Hexazinone can persist for months in soil, ground water and streams in detectable concentrations. Soil and aquatic metabolism produces several metabolites. Hexazinone is mobile in most soils and can leach to depths approximating one m under heavy rainfall conditions. Extensive field monitoring in California documents concentrations of hexazinone commonly in the non-detectable to 5 ppb range in buffered streams and slightly lower in ground water. Soil application under or near the target plant is the primary mode of treatment.

Information Sources

A variety of secondary information sources are the primary basis for this summary. Sources selected focus on streams, rather than lakes, to be more directly relevant to potential herbicide use by federal land management agencies. Results of extensive field monitoring of hexazinone in forest streams in the Sierra Nevada and North Coast ranges of California and elsewhere are described. Several older primary sources offer field monitoring information on hexazinone levels in soil. Although a US EPA Reregistration Eligibility Decision exists for hexazinone, because of its relatively early publication date, 1994, it is supplemented by the other information sources.

Disposition in Soil

Similar to many herbicides, the principal mechanism of hexazinone break down in soil in ambient conditions is microbial metabolism (SERA 1997, Neary et al. 1993, Information Ventures, Inc. 1995). US EPA (1994:22) identified four metabolites of hexazinone from aerobic soil metabolism and additional metabolites produced through aerobic and anaerobic aquatic metabolism.

Persistence

Hexazinone can persist in soil for months. It has been labeled "... of moderate to high persistent" (Extoxnet 1996) and "persistent" (Information Ventures, Inc. (1995). Break down rate is strongly temperature-dependent; in a laboratory study Bouchart et al. (1985, cited in SERA 1997:4-10) documented soil half-lives increasing from 76 and 77 days (for sandy and silt loams at 30C) to 502 and 426 days (for the same soils at 10C). Field dissipation rates, involving degradation and transport, appear to be much faster (SERA 1997), consistent with relatively high mobility. Several reported field half-lives are:

- 186 days in northern climates in sandy soil (Helbert et al. 1990, cited in SERA 1997:4-13)
- 55 and 265 days for bare and litter-covered soil respectively (US EPA 1994:24)
- <30 to 180 days, with a representative value of about 90 days (Extoxnet 1996)
- 11-180 days in southern climates at application rates of 1.6 to 2.9 kg/ha (Michael and Neary 1993)
- 10-30 days in four forest watersheds in Georgia (Neary et al. 1983, cited in SERA 1997:App. 6-11)
- < 30 days generally, but potentially up to six months, "depending on soil and climatic conditions" (Neary et al. 1993)
- 1-6 months (Information Ventures, Inc. 1995)

There is evidence of irregular fluctuations of hexazinone concentrations in soil over periods of one year or longer, with peak levels occurring up to several months after application (SERA 1997:3-22, citing several sources).

Other evidence documents the long-lived nature of hexazinone in some situations. "Hexazinone may remain in the soil at low concentrations for up to three years after application" (Information Ventures, Inc. 1995). Feng and Navratil (1990, cited in SERA 1997:App. 6-6) measured detectable concentrations of hexazinone in the 15-30 cm layer of an Alberta Canada soil 360 days after application. These authors hypothesized that the long dissipation time was probably due to late application of the herbicide in autumn and frozen ground in winter. In a separate study in Alberta, Feng et al. (1989, cited in SERA 1997:App. 6-6) documented detectable hexazinone to 80 cm soil depth at the end of a 448-day monitoring period. Over a one-year period after initial dissipation of hexazinone in an Arkansas stream study, hexazinone concentrations "...remained relatively constant (ca. 0.2-0.5 ppm after an application of 2.0 kg active ingredient/ha or about 0.1-3 ppm/lb active ingredient applied)" (SERA 1997:4-13, citing Bouchard et al. 1985).

Mobility and Leaching

Most sources describe hexazinone as likely to be mobile in most soils (e.g., US EPA 1994:vii, Extoxnet 1996, Information Ventures, Inc. 1995) or "moderately mobile" (Linders et al. 1994, cited in Ganapathy 1996:2). The binding, and therefore the mobility, of hexazinone is nevertheless strongly dependent on soil conditions (SERA 1997). Similarly, several sources describe hexazinone as being a potential leacher (Diaz-Diaz and Loague 2001, Ganapathy 1996:2), and exhibiting a "strong possibility of movement to ground water ..." (US EPA 1994:vii).

Hexazinone leaching depths vary, with Information Ventures, Inc. (1995) noting hexazinone "is not likely to leach beyond the root zone ..." and Feng 1987 (cited in SERA 1997:4-11) adding that field tests showed most hexazinone, and its metabolites, remaining "... in the 5-10 cm thick surface duff and humus." Other results report deeper penetration—

- 80 cm under conditions of greater rainfall or snow melt (Feng et al. 1989b, cited in SERA 1997:4-11)
- 150 cm per lysimeter studies under conditions simulating very heavy rain (Stone et al. 1993, cited in SERA 1997:4-11).

Sub-surface lateral movement of hexazinone varies and may depend on slope gradient. Feng (1987, cited in SERA 1997:App. 6-5) found no quantifiable concentrations of hexazinone 20 m outside the treatment plot during a 104-day monitoring period. Bakke (2001) described lateral

movement at one site (of many) as about 450 ft from the treated unit. Williamson (1988, cited in SERA 1997:4-13) described lateral movement as less significant than downward movement. Bush et al. (1995:115) observed significant lateral movement of hexazinone when slopes exceeded 2%. Harrington et al. (1982, cited in SERA 1997:4-12) probably best summarized lateral movement as depending "... on rainfall and soil slope."

Soil Water Concentrations

Detectable concentrations of hexazinone in soil water are commonly reported with peak concentrations sometimes occurring months after application. In lysimeter measurements Stone et al. (1993, cited in SERA 1997) quantified a "worse case" condition of hexazinone leachate ranging from 10-80 µg/l. In this study, and others, peak concentrations were delayed and appeared to depend on the timing, frequency, and magnitude of rainfall (SERA 1997:3-20). Bush et al. (1995) measured soil water concentration peaks in the 100-200 ppb range, typically within 3 months of hexazinone application.

Disposition in Water

Persistence

Hexazinone can persist in surface and ground waters for many months, although "persistence" may be a misnomer. Hexazinone may bleed into surface waters from groundwater or other sub-surface sources rather than actually persisting in water for long durations. In field studies hexazinone was reported in surface water "... for over a year" at low levels in Arkansas (Bouchard et al 1985, cited in Neary et al. 1993:415), up to 11 months elsewhere in the South (Neary et al 1983, cited Ganapathy 1996:10), "... during periods of higher [stream] discharge through the end of the 1.3 year study" (Bouchard et al. 1985b, cited in Ganapathy 1996:9) and "... up to 36 months after application ..." (Lavy et al. 1989, cited in Ganapathy 1996:9). Describing results of monitoring in the Sierra Nevada, Bakke (2001) stated "[I]t appears ... that groundwater can continue to feed hexazinone into surface water over a long period of time, regardless of implementation of BMPs to directly protect surface water." Hexazinone persisted "... for almost 10 years" at sites on the Eldorado National Forest in California (Podsiadlo 2003).

Year-plus durations of hexazinone in ground water are reported from Arkansas (Bouchard et al. 1985, cited in Neary et al. 1993:419) and Florida (Neary et al. 1993), although the Florida detections did not begin until a year after application.

Surface Water Concentrations

Hexazinone is detectable in stream water after application at sites with normal buffers in place (e.g., Bouchard et al. 1985b, cited in Ganapathy 1996, Lavy et al. 1989, cited in Comerford et al. 1992). "There seems to be no systematic differences [in hexazinone concentrations] associated with the formulation (liquid or granular) or specific water types (i.e., streams or lakes)" (SERA 1997:3-20). Because of its common use, water monitoring results for hexazinone are well documented and indicate ambient hexazinone concentrations commonly in the 1-40 µg/l range per pound of acid equivalent applied (SERA 1997). Field monitoring of buffered streams in the Sierra Nevada often show concentrations in the 0.1 to 5 ppb range for ground-applied hexazinone (Appendix D). Nevertheless, detectable hexazinone was not found downstream of a treated and buffered fine loam soil at a coastal plain site in South Carolina (Bush et al. 1995). Also, none of 108 samples collected in the 1998 and 1999 in the Trinity, Scott, and Klamath River watersheds

in northern California had detectable hexazinone (Jones et al. 2000) and some buffered sites in the Sierra Nevada had non-detectable concentrations (Appendix D).

Ground Water Concentrations

Reported ground water concentrations of hexazinone commonly range from 10-40 μg/l. In their Arkansas field study Bouchard et al. (1985, cited in Neary et al. 1993:419) never reported concentrations exceeding 14 μg/l in ground water entering perennial streams. At a Florida site with sandy soils, hexazinone concentration ranged between 17 and 35 μg/l in surficial, unconfined ground water (Neary et al. 1993:419-420). And "[G]roundwater detections have been reported in Hawaii (0.06-0.72 ppb), Florida (0.12-2.90 ppb), Maine (0.2-29 ppb), and North Carolina (0.74-34 ppb); levels well below the Health Advisory (200 ppb)" (US EPA 1994:vii).

One-quarter of over 100 sub-surface water samples collected from numerous forested sites in the Sierra Nevada between 1991 and 1999 had detectable concentrations of hexazinone (Bakke 2001). Most concentrations were low, with the maximum equaling 2.1 ppb.

Metabolites

The limited available information on the environmental fate of metabolites of hexazinone suggests that metabolite disposition parallels that of hexazinone. Leaching depths vary—"No ... hexazinone metabolites (A or B) were detected in soil below 15 cm" (Feng 1987, cited in SERA 1997:4-11) in one report but "metabolites ... leached to a depth of 75 cm in soil ..." (US EPA 1994:23) in another report. Lateral mobility of both hexazinone and its metabolites was similar--neither was detected 20 m outside and downslope from the treatment plot--in Feng's Alberta study (1987, cited in SERA 1997:App. 6-4). Concentrations of the metabolites may be slightly lower in soils and surface waters than the parent hexazinone:

- "Metabolites A, A-1, B, C, and 1 were identified in soils at maximum concentrations of 0.04, 0.21, 0.31, 1.23, and 0.71 ppm, respectively" (US EPA 1994:23)
- "... much lower levels [vs. hexazinone] of two hexazinone metabolites, were detected in runoff water during the first month after application (SERA 1997:3-20, citing Neary et al. 1983)

Imazapic

Overview

Relatively little information is available on the fate of imazapic in soil and water. Imazapic is described as "moderately persistent" in soil, with limited mobility because it binds to soil particles. No environmental fate information was found on the one identified metabolite of imazapic. No known ground or surface water field monitoring data are available for imazapic in forested environments. Simulation of imazapic movement to an un-buffered pond suggest that ambient water concentrations of imazapic, normalized at 1 lb acid equivalent/acre, could range from 0.1 and 45 μg acid equivalent/l, depending upon soil type. Foliar application is the primary mode of treatment.

Information Sources

The following summary is taken largely from two secondary sources. There are no known field studies of imazapic use in forested environments. No US EPA Reregistration Eligibility Decision is available for imazapic and few other primary or secondary sources of information on imazapic appear to be available.

Disposition in Soil

Imazapic is degraded in soil primarily by microbial metabolism. It does not volatilize from the soil surface and photolytic breakdown on soils is negligible (Tu et al. 2001). Imazapic "... is not degraded by other abiotic chemical reactions ..." (American Cyanamid 2000, cited in Tu et al. 2001:7G4). In studies of animal excretions, a major metabolite of imazapic "was characterized as a hydroxymethyl analog in feces that accounted for 10% of residue" (SERA 2001:3-6).

Persistence

Imazapic is described as "moderately persistent in soils" (Tu et al. 2001:7G3). Half-lives for imazapic in soils are given as:

- 113 days in an aerobic, sandy loam (Ta 1997, cited in SERA 2001:3-21)
- 120 days due to photolysis (Tu et al. 2001)
- 31 to 233 days depending upon soil characteristics and environmental conditions (American Cyanamid 2000, cited in Tu et al. 2001)
- "7 to 150 days depending upon soil type and climatic conditions" (Tu et al. 2001:7G4)

Mobility and Leaching

Imazapic appears to exhibit limited mobility and leaching potential. It is described as showing "little lateral movement in soil" (American Cyanamid 2000, cited in Tu et al. 2001:7G4), and "... generally moves just 6 to 12 inches, although it can leach to depths of 18 inches in sandy soils" (R. Lym, pers. comm., cited in Tu et al. 2001:7G4). Barnes (undated) reiterated that imazapic's "...mobility in earth is limited because it binds to soil particles."

Disposition in Water

Persistence

The limited available information suggests that imazapic is moderately persistent in water. It is soluble in water and is not degraded hydrolytically in aqueous solution. Imazapic is quickly photodegraded by sunlight with a half-life of one to two days (Tu et al. 2001). US EPA (1995a, cited in SERA 2001) listed 30 days as the half-live for imazapic in water.

Surface Water Concentrations

No field monitoring data for ground or surface water in forestland environments are known. GLEAMS modeling results—without a streamside buffer zone--suggest that "at higher rainfall rates [above about 10 inches/yr], plausible offsite movement of imazapic results in runoff losses that range from about 0.01 to 0.45 of the application rate, depending primarily on the amount of rainfall rather than differences in soil type" (SERA 2001). The same modeling (without a streamside buffer zone) estimated concentrations of imazapic in ambient water (µg/l) as a function of annual rainfall and soil type using a normalized application rate of 1 lb acid equivalent/acre as follows (SERA 2001) as shown in Table E-1.

Table E-1. Estimated concentrations, without a streamside buffer zone, of imazapic in ambient water.

	Concentrations in Ambient Water (µg a.e./l per lb a.e./acre)					
Annual Rainfall (in.)	**Clay**		**Loam**		**Sand**	
	Average	Maximum	Average	Maximum	Average	Maximum
15	0.100	0.304	0.000	0.000	0.000	0.000
20	0.473	1.489	0.280	0.595	5.374	12.363
25	0.768	2.577	0.968	1.758	7.306	16.999
50	2.124	8.757	3.468	6.682	9.001	38.627
100	4.005	20.597	5.152	12.734	9.430	51.360
150	5.183	30.140	5.756	15.663	9.546	56.195
200	5.990	39.186	6.071	17.299	9.598	58.818
250	6.579	46.161	6.271	18.461	9.629	60.136

The 1 lb acid equivalent/acre application is higher than the normalized rate that would normally be used in most applications by federal land management agencies.

Imazapyr

Overview

Although imazapyr often persists in soils, it is typically described as being minimally mobile. In water imazapyr breaks down to two dozen degradates, none of which are described as being persistent in water. Results from the limited known surface and ground water monitoring of ground-applied imazapyr suggest low or non-detectable concentrations of the chemical persist in forest streams with buffers. Foliar application is the primary mode of treatment.

Information Sources

A recent US EPA Reregistration Eligibility Decision is not available for imazapyr and data from only a few forestland water monitoring studies are known. This assessment is based primarily on secondary sources and three primary studies of imazapyr disposition in soil.

Disposition in Soil

Imazapyr "...is chemically stable in soil and microbial breakdown along with dispersive processes such as percolation and runoff will be the primary mechanisms in the decrease in imazapyr in soil over time" (SERA 1999:4-15). Laboratory studies by McDowell et al. (1997) showed that temperature appreciably affected degradation rates, whereas soil organic matter and pH were less influential.

Persistence

Imazapyr has been described as a persistent herbicide, with at least one study recording detectable, but low, concentrations of the chemical for one year after treatment. Cox (1996) described imazapyr as "... a persistent herbicide." She cited persistence ranges from 60 to 436 days (US EPA 1984, Coffman et al. 1993, Lloyd et al., all cited in Cox 1996) for studies from

southern and northeastern states. "Imazapyr can remain active in the soil for six months to two years" (Information Ventures, Inc. 1995). Residues were "... periodically detected (< 10 ppb) in lysimeters [in unsaturated soil solution] for one year following application", although "[N]o detectable imazapyr residues were observed ... in groundwater approximately two years following application" (Wiley et al. 2000).

Half-lives for imazapyr are highly variable, depending upon the parameters of each study:

- 125 and 69 days at 15C and 30C respectively in silt loam soil with high organic matter (6.4% organic carbon) (McDowell et al. 1997)
- 155 and 77 days at 15C and 30C respectively in silt loam soil with low organic matter (3.5% organic carbon) (McDowell et al. 1997)
- 17 months, per laboratory tests in dark, anaerobic conditions (American Cyanamid 1983b, cited in SERA 1999:App. 5-3)
- 21 days to 49 months, per field studies (US EPA 1984, Vizantinopoulos and Lolos 1994, both cited in Cox 1996:19)
- 90 days (Knisel et al. 1992, cited in SERA 1999: 2-4)
- 210 days—laboratory analysis of an aerobic soil (American Cyanamid 1983b, cited in SERA 1999: 2-4)
- 30 days (Michael et al. 1996, cited in SERA 1999: 2-4)
- 34-65 days (Michael and Neary 1993, cited in SERA 1999: 2-4)

Cox (1996:18) maintained that half-life measurements for imazapyr might be conservative because the chemical "... persisted in most cases, until the last date tested," implying longer half-lives than those typically quantified.

Mobility and Leaching

Sources document variable mobility and leaching of imazapyr in soils, probably because the binding of imazapyr to soil is complexly dependent upon a variety of soil properties. Field measurements showed "... no indication of subsurface lateral flow" (Wiley et al. 2000:300) at the interface of sand and clay-enriched soil layers in the Georgia upper-coastal plain. And imazapyr was described as "... not as mobile ... in shallow wells as were hexazinone or picloram" (Wiley et al. 2000:300). In another Georgia upper-coastal plain study, Bush et al. (1995) stated that "... imazapyr showed limited potential for lateral movement or movement to the 8' perched water table." And imazapyr was described as having "... a low potential for leaching into ground-water" (Information Ventures, Inc. 1995). On the other hand, Cox (1996:19) stated "[O]ne field study found that between 40 and 70 percent of applied imazapyr leached down to the lowest depth tested (45 cm)" and "[A]nother study found that 'significant' residues of imazapyr leached to a depth of between 1.5 and 3 m depending on application rate" (Rahman et al. 1993, cited in Cox 1996:19). SERA (1999:App. 5-2) noted that binding of soil to imazapyr increases with decreasing pH, increasing iron oxide levels, and elevated organic matter at lower pH. Wehtje et al. (1987, cited in SERA 1999:App. 5-2) associated decreased soil water content with enhanced soil binding.

Disposition in Water

Persistence and Metabolites

SERA (1999:3-15) listed photolysis as the major mechanism for breakdown of imazapyr in water and cited 28 days as the half-life of imazapyr in pond water (American Cyanamid 1991, cited in SERA 1999:3-18). Information Ventures, Inc. (1995) listed about four days as the half-life of

imazapyr in water. In their Georgia field study Wiley et al. (2000) collected both flume and stream samples after aerial application of imazapyr at 2.2 oz active ingredient/acre. Two flume samples from 11 storm events collected over a 7-month period contained "trace levels" of 2.5 to 5.0 ppb; all other flume samples had non-detectable residues (<2.5 ppb).

SERA (1999:3-15) noted that "... there appear to be at least 25 photolytic breakdown products of imazapyr ... " but that "... these breakdown products ... are not persistent in water." Major breakdown products include quinolinic acid and a furo (3,4-b) pyridin-5 (7H)-one-7-hydroxy compound (SERA 1999:3-15).

Surface Water and Groundwater Concentrations

Little field monitoring data exist for imazapyr under operational forestry conditions, although the existing information suggests low or non-detectable concentrations of imazapyr in surface water from application sites with buffer zones (Appendix D). Aerial applications at four locations in Alabama and Washington state had stream concentrations of imazapyr varying from no more than 1 µg/l at two buffered sites in Washington (Rashin and Graber 1993, cited in SERA 1999:3-17) to 680 µg/l at an un-buffered Alabama location (Michael and Neary 1993, cited in SERA 1999:3-17). In the Wiley et al. (2000) Georgia study of buffered streams with aerially-applied imazapyr, no samples collected between 2 weeks and 10 months post-application contained residues > 5 ppb although one flume sample had imazapyr at 7 ppb. Bush et al. (1995) found no detectable concentrations (@ 5 ppb detection limit) of imazapyr in stream samples downstream of their buffered ground application site.

One of over 830 samples from wells 4' and 8' deep had a detectable concentration (8.6 ppb) over a 1 ½-year period after imazapyr application at buffered Georgia coastal plain sites (Bush et al. 1995).

GLEAMS modeling of imazapyr percolation and runoff to a 1-m deep pond immediately adjacent to an application site generated peak concentrations, at 100" annual rainfall, of "...about 0.017 mg/l for runoff from clay and 0.06 mg/l for percolation through sand [0 runoff is estimated for sand]" (SERA 1999). GLEAMS results for off-site movement of imazapyr are illustrated below (Figure E-1).

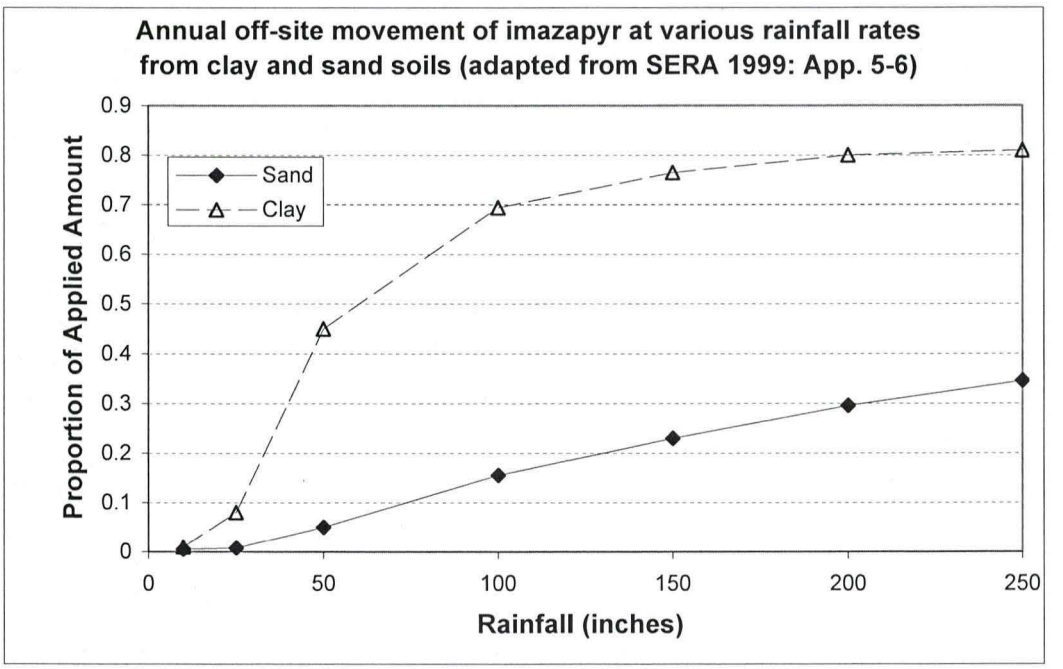

Figure E-1. Off-site Movement of Imazapyr (SERA 1999).

The GLEAMS modeling simulates an un-buffered pond, not the typical stream environment common to most herbicide applications on federal lands, and presumes aerial application.

Metsulfuron methyl

Overview

Persistence of metsulfuron methyl in soil is variable with documented half-lives ranging from 10 days to 10 months and low concentrations at the longer periods. Leaching of metsulfuron methyl to below 1 m soil has been documented in South Carolina in common soil types. The only known field monitoring (in Florida) of ground-applied metsulfuron methyl in forest streams documented low concentrations (<10 ppb), with over 99% of the samples having non-detectable concentrations. Modeling suggests the potential for off site movement of metsulfuron methyl, primarily by percolation. Foliar application is the primary mode of treatment.

Information Sources

The following summary is taken largely from two secondary sources, and a recent study on soil transport and dissipation of herbicides used to control kudzu in the southern United States, Bush (2001). A US EPA Reregistration Eligibility Decision is not available for metsulfuron methyl.

Disposition in Soil

The degradation rate of metsulfuron methyl in soils is variable and depends on soil temperature, moisture content, and pH. Microbial activity and hydrolysis are degradation mechanisms for metsulfuron methyl. Adsorption to clay is low (Information Ventures, Inc. 1995). Breakdown is faster in acidic soils with higher temperature and moisture content (Smith 1986, cited in Extoxnet 1996). Microbial activity is about one-half as influential as physical processes in determining

degradation rates (numerous citations in SERA 2000:App. 2-3) and degradation rates are negatively correlated with soil pH (several citations in Bush 2001:6). SERA (2000:App. 2-2) reiterated "[T]he binding of metsulfuron methyl to soil is highly variable, depending primarily on pH and organic carbon." Two environmental metabolites of metsulfuron methyl, saccharin and benzoic acid, are identified in SERA (2000).

Persistence

Persistence of metsulfuron methyl in soil is also variable (SERA 2000:App 2-2) and detectable concentrations of metsulfuron methyl can extend for months at low levels. Soil half-lives are given as—

- 10-38 days (USDA/ARS 1995, cited in SERA 2000:App 2-3)
- one month to somewhat over 10 months in field studies by Rapisarda and Scott (1986, cited in SERA 2000:App 2-3)
- ranging from 14 to 180 days, with an overall average of 30 days (Wauchope et al. 1992, cited in Extoxnet 1996)
- 120 to 180 days (in silt loam soil) (Information Ventures, Inc. 1995)

"Metsulfuron methyl persisted at 0.025-0.1 ppb for 182-353 days in shallow lysimeters [51-58 cm] and at 0.025-0.07 ppb for 182-300 days in deep lysimeters [84-109 cm]" in Bush's S. Carolina field study (Bush 2001:1). Others studies document metsulfuron methyl persistence in the upper 1 foot of soil for up to one year, although movement of the chemical through some soils can be relatively fast under high rainfall conditions (Sahid and Quirinus 1997, Walker and Welch 1989, both cited in SERA 2000:4-13).

Mobility and Leaching

Field and modeling studies suggest that metsulfuron methyl may leach to soil depths of 100 cm, although concentrations of the chemical are low at the greater depths. Bush (2001:6) measured metsulfuron methyl in lysimeters 84-109 cm deep "... at very low concentrations." In another lysimeter study, Bergstrom (1990, cited in SERA 2000:App. 2-6) "noted leaching of about 0.02% to 0.06% of the applied amount of metsulfuron methyl after a cumulative rainfall plus watering of 447 mm ... ." Pool and DuToit (1995, cited in SERA 2000:App. 2-6) stated "... in some high pH soils, metsulfuron methyl may leach to a depth of 240 mm after a single simulated rainfall of 20 mm." Moreover, in a literature review Bergstrom and Stenstrom (1998, cited in SERA 2000:App. 2-6) suggested that up to 6% of applied metsulfuron methyl might leach though soil. GLEAMS modeling results support these findings and suggest "... that metsulfuron methyl may leach below 12 inches in both clay and sandy soil at relatively high rainfall rates" (SERA 2000:App. 2-6). Information Ventures, Inc. (1995) noted that metsulfuron methyl leaches through silt loam and sand soils and can contaminate ground water at very low concentrations. Bush (2001) monitored four herbicides concurrently and determined the "... relative potentials of herbicides to move into shallow groundwater [was]: picloram > metsulfuron methyl > clopyralid > triclopyr."

Disposition in Water

Persistence and Degradation

Metsulfuron methyl is degraded in natural waters by hydrolysis and photolysis. The chemical may persist in water one year (Bastide et al. 1994 and Du Pont 1985a,b, c, both cited in SERA

2000:3-12), although it has a half-life of 3 weeks at pH 5.0, 25°C and >30 days at 15°C (US EPA 1989, cited in Extoxnet 1996). Thompson et al. (1992) reported 84 day (at application rate = 1 mg/l) and 29 day (at application rate = 0.01 mg/l) half-lives for metsulfuron methyl in experimental enclosures in a mixed wood/boreal forest lake. These authors attributed the persistence of metsulfuron methyl to low light intensity and short day length. Differences in hydrodynamics between lakes and streams (e.g., mixing and dilution in streams) cautions against extrapolating results from lakes to the stream environment common to herbicide applications by federal land agencies.

GLEAMS modeling suggests that detectable amounts of metsulfuron methyl are possible in water one year after application. However, extending the modeling for a 6-year period, with metsulfuron methyl applied annually on July 1, showed "no accumulation of metsulfuron methyl in water with repeated yearly applications" (SERA 2000:App. 2).

Surface and Ground Water Concentrations

The very limited known field monitoring of metsulfuron methyl in forest streams documents low concentration of ground-applied metsulfuron methyl (Appendix D). Michael et al. (1991, cited in Michael submitted) reported peak metsulfuron methyl concentrations in surface waters of 8 ppb from a study in the northern Florida lower coastal plain. In these experiments, 227 of 229 samples had non-detectable metsulfuron methyl concentrations.

GLEAMS modeling estimated about 0.006 mg/l for maximum worse case metsulfuron methyl concentrations (both sand and clay soils in ambient water), at an application rate of 0.02 lb active ingredient/acre (SERA 2000:3-13). The modeling further suggested, "... that both runoff and percolation could be significant depending on the soil type and estimates of metsulfuron methyl binding to soil" (SERA 2000:App. 2-1). GLEAMS estimates of annual off-site transport loss of metsulfuron methyl as a proportion of the applied amount are illustrated by annual rainfall (Figure F-2). For both soils, "... the primary mode of transport is percolation, with very little off site movement of the compound in runoff" (SERA 2000:App. 2-10).

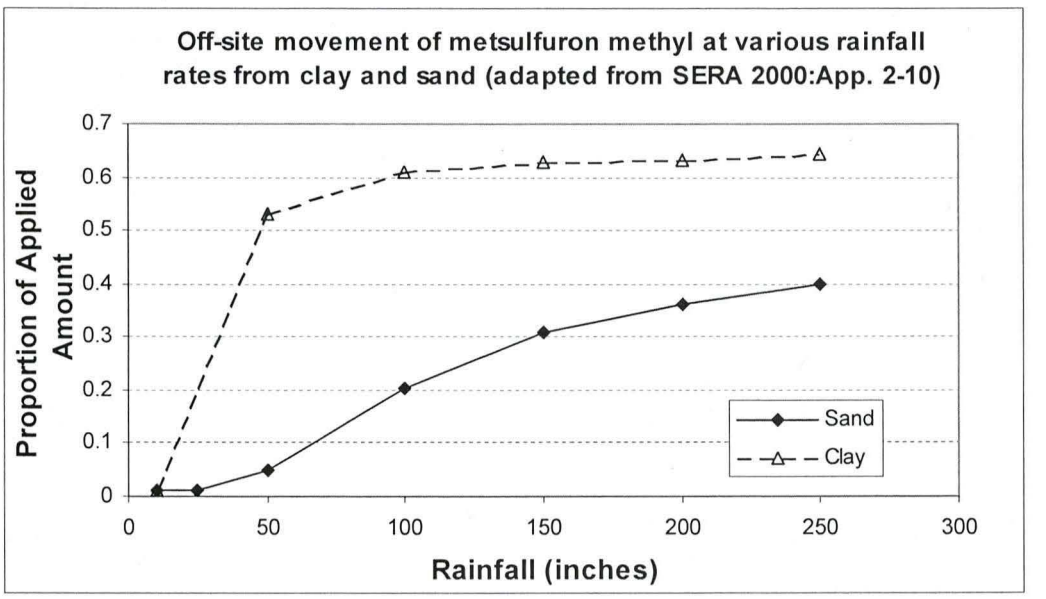

Figure F-2. Off-site movement of metsulfuron methyl (SERA 2000).

Bush (2001:6) described metsulfuron methyl as having "... the potential to contaminate groundwater associated with shallow water tables," but further cautioned "... very low concentrations were detected in our study."

Picloram

Overview

Water quality monitoring of picloram in the southern United States suggests that detectable concentrations of the chemical can occur in surface waters in some situations. Picloram can persist in soils for years and in some situations may be "...nearly recalcitrant to all degradation processes" (US EPA 1995:44). Picloram was described by US EPA (1995:41) as "... among the most mobile of currently registered pesticides." It can leach to significant soil depths. Picloram has been found in stream water 1 or more km distant from the point of application. Limited results of monitoring buffered streams after ground-applied picloram document maximum concentrations of picloram $\leq$ 10 ppb. Foliar application is the primary mode of treatment.

Information Sources

A variety of secondary information sources are the primary basis for this summary. Several primary sources addressing the leaching and mobility of picloram and its dissipation in the aquatic environment are included. Although a US EPA Reregistration Eligibility Decision exists for picloram, because of its relatively early publication date, 1995, it is supplemented by the other information sources. Results of field monitoring of picloram in forest streams are discussed.

Disposition in Soil

Photodegradation appears to be a primary mechanism for break down of picloram in soil (Information Ventures, Inc. 1995, Woodburn et al. 1989). Johnsen and Warskow (1980) reported that "... sunlight decomposed 57% of the picloram after 8.8 hr of sunlight exposure" although photodegradation, according to Extoxnet (1996, citing Weed Science Society of America 1994) "...is significant only on the soil surface".

Picloram acid and its derivatives, including triisopropanolamine picloram (TIPA-salt), isooctyl/ethylhexyl picloram (IOE) and potassium picloram (K-salt), "... are expected to be similar in their biological and chemical characteristics in the environment" (US EPA 1995:41). More specifically, except for IOE, the other three compounds dissociate in the environment to yield the free anion. "IOE is expected to degrade rapidly (measured aerobic half-life 2 days), to form the same anion as the acid and the salts. Consequently, IOE is expected to have environmental fate characteristics very similar to those of the other active ingredients" (US EPA 1995:42). In this summary of environmental fate, the term "picloram" refers to picloram acid and the three derivatives.

Persistence

Although picloram degrades quickly in sunlight, in some soils it otherwise may be "...nearly recalcitrant to all degradation processes" (US EPA 1995:44) and persist for years. "Picloram can stay active in soil for a moderately long time, depending on the type of soil, soil moisture and

temperature. It may exist at levels toxic to plants for more than a year after application at normal rates" (Information Ventures, Inc. 1995). Extoxnet (1996) described picloram as " ... moderately to highly persistent in the soil environment, ..." and Cox (1998:13) labeled it "persistent." Half-lives in soil include:

- 20 to 300 days, with an estimated average of 90, per field measurements (Extoxnet 1996, citing Wauchope et al. 1992)
- 21-278 days, "in most cases ... over 100 days" (Cox 1998:18, attributed to US EPA undated, Cryer et al. 1992, Johnsen 1980, Michael et al. 1989)
- 167 to 513 days in seven aerobic soils (US EPA 1995:42)

Picloram has been detected for years after application in soil. Detectable field concentrations of picloram were reported as 840 days, 790 days and 9 months after application, in the deepest samples (1.8 m, 1.2-1.5 m and 0.95 m respectively), in forestry studies in South Carolina, Montana, and Washington (US EPA 1995). In anaerobic soil conditions, picloram can be stable, "... with over 90% of the chemical not degraded after 300 days of incubation" (USEPA 1995:42). In more recent studies, Close et al. (1998) recorded leaching of picloram to 1.3 m depth 600 days after application to a fine sandy loam soil in New Zealand, and Bush (2001) found picloram at 0.6 to 2.5 ppb concentration 1 m deep "for at least 10 months after the initial application" in his S. Carolina field study. These persistence lengths may be minimum estimates to the extent that in some studies picloram was still being detected at the last sampling date (Cox 1998).

A variety of factors influence picloram persistence. Increased persistence can be due to--

- "Alkaline conditions, fine textured clay soils, and a low density of plant roots ..." (Information Ventures, Inc. 1995)
- elevated soil organic matter levels, which increase the sorption of picloram (Extoxnet 1996, citing Weed Science Society of America 1994)
- finer soil textures (e.g., clays vs. sands) (US EPA 1995:43).

Application rate inversely affects persistence (Krzyszowska et al. 1994, cited in SERA 1999:4-3, Weed Science Society of America 1994, cited in Extoxnet 1996). Mayes and Oliver (1985) added climate to the list of factors influencing the environmental persistence of picloram.

Mobility and Leaching

Most sources describe picloram as very mobile, and use descriptions such as "... among the most mobile of currently registered pesticides ... "(US EPA 1995:41), "... one of the most mobile of pesticides" (Bush 2001:10), "... extremely mobile under field conditions" (Cox 1998:19, attributed to US EPA 1995) and "... extremely mobile in soil" (SERA 1999:4-12). In a different opinion Mayes and Oliver (1985) described picloram as moderately mobile in soil. Bush (2001) monitored four herbicides concurrently and determined the "... relative potentials of herbicides to move into shallow groundwater [was] picloram > metsulfuron methyl > clopyralid > triclopyr."

Rate and direction of picloram movement are partly a function of soil organic matter and texture, with leaching greatest for alkaline, highly permeable, sandy, or light-textured soils with low organic matter content (Information Ventures, Inc. 1995). Nevertheless, "[W]hile it is plausible that substantial differences will be evident between extremely different soil types such as clay and sand, no substantial differences in soil mobility between sandy loam soil (76.9% sand, 1.7% OM, pH 5.2) and loam soil (24% sand, 5.7% OM, pH 7.2) were noted in a study by Gallina and Stephenson (1992)" (SERA 1999:4-13).

Picloram can leach to significant soil depths. Bush (2001) found picloram at the lowest (84-109 cm) of his two sets of soil lysimeters in 65 of 103 samples collected—although he noted that 85% of the samples had low residue levels, $\leq$ 2.5 ppb. Picloram was detected at 1.3 m soil depth in New Zealand silt loam and fine sandy loams (Close et al. 1998). Cox (1998:19, attributed to US EPA 1995) generalized that picloram "... often leaches to the deepest part of the soil profile sampled." The combination of high solubility in water and high mobility under laboratory and field conditions supports the field findings that leaching is a major route of picloram dissipation (US EPA 1995:42).

Disposition in Water

Degradation and Persistence

Although laboratory studies demonstrate rapid degradation (e.g., half-life < 3 days) of picloram in water by sunlight (Extoxnet 1996, citing Howard 1991 and Weed Science Society of America 1994), US EPA (1995:45) noted, "[O]nce in ground water, the chemical [picloram] is unlikely to degrade even over a period of several years."

In field studies, picloram has been found in ground and surface water at some locations for months after application. For instance, "[P]icloram (0.25-88.3 microgram/liter) was recovered after 35 months from groundwater samples collected at 120 cm" approximately 1 km from the treatment area in a study in northern Saskatchewan (Smith et al. 1988). And Cox (1998:18, citing Dennis 1977) reported detecting picloram in a stream in a West Virginia pasture 275 days after application. Although most studies find picloram to be long-lived, "... picloram was not detected in the surface or groundwaters during the 90 d following application" in a roadside weed control project in the northern Rockies (Watson et al. 1989).

Ground Water Concentrations

Data for ground water occurrence of picloram is relatively scarce although in the early 1990s picloram had been reported in ground water from 11 states, at concentrations ranging from 0.01 to 49 µg/l (Howard 1991, cited in Extoxnet 1996). US EPA (1992, cited in US EPA 1995) reported detections up to 30 ppb in 10 states. Across the US through 1998, the US Geological Survey (2000) detected picloram, with a maximum concentration = 0.0022 mg/l, in 0.2% of 2536 ground water samples. No detectable picloram was found in samples from watersheds described as having any forestland use or being a "forested indicator area."

Surface Water

Monitoring data and modeling results are available for estimating picloram surface water concentrations and disposition of picloram downstream from treatment locations. Limited monitoring of buffered streams by ground application document potential detectable amounts of picloram. Modeling results suggest that contamination of ground or surface water by picloram is not likely in areas with annual rainfall less than 50 inches.

Monitoring Picloram in Surface Waters

Across the US through 1998, the US Geological Survey (2000) detected picloram, with the maximum concentration = 0.0027 mg/l, in 0.15% of 3384 surface water samples. No detectable picloram was found in samples from watersheds described as having any forestland use or being a "forested indicator area." No picloram was detected (@ 0.00005 mg/l detection limit) in a series

of prairie lakes in Saskatchewan (Donald and Syrgiannis 1995, cited in SERA 1999:3-14). These two "background" studies assessed surface waters having no known picloram application.

In contrast, field measurements adjacent to sites with known picloram treatment routinely—although not uniformly--detect the chemical. At sites in the southern US 2.2 mg/l per lb/acre was the peak concentration (normalized for application rate) reported for broadcast ground application by Michael and Neary (1993, cited in SERA 1999). Results of five studies in S. and N. Carolina (Appendix D) document maximum concentrations of picloram from non-detectable to 10 ppb (Bush et al. 1995, Neary et al. 1985). Higher peaks were reported for injection and broadcast aerial application. In contrast, at chaparral watersheds in Arizona, Davis and Ingebo (1973, citied in SERA 1999) reported a maximum normalized picloram concentration of 40 µg/l per lb/acre in stream water, much lower than the southern US findings. Watson et al. (1989) detected no picloram in streams after application in loam or sandy loam soils (@ 0.0005 mg/l detection limit). SERA (1999:3-15) attributed these differences to rainfall patterns and location conditions affecting runoff potential.

Modeling Picloram in Ponds

"Based on the results of the GLEAMS modeling, contamination of ground or surface water from clay or sand is not likely in areas with annual rainfall of less than 50 inches" (SERA 1999:3-16). In the simulation, peak concentrations occurred between 40 and 50 days after application. These results assume a picloram application rate of 1 lb acid equivalent/acre and a dissipation half-life of 15 days.

Combined modeling and monitoring results suggest that with an application rate of 1 lb acid equivalent/acre, long term (one year), time-averaged picloram surface water concentrations "... are likely to be in the range of 0.01 to 0.06 mg/l in areas with substantial rainfall or as the result of applications in which some initial incidental contamination of water occurs (SERA 1999:xvii)."

Hexachlorobenzene

Hexachlorobenzene is a contaminant in technical grade picloram that "... has been classified as a potential human carcinogen by the US EPA" (SERA 1999:xi). Although hexachlorobenzene has an initial half-life of about 7 days in the upper 1 cm of soil (SERA 1999), once absorbed into the soil column, hexachlorobenzene can persist for 3 to 6 years (ATSDR 1998, cited in SERA 1999:3-23 and Cox 1998). Cox (1998, attributed to ATSDR 1998) asserted that hexachlorobenzene could persist in ground water up to 11 years. Because hexachlorobenzene binds to soil and is relatively immobile in soils, it is not likely to percolate through soils to contaminate ground water directly (ATSDR 1998, cited in SERA 1999:3-26). However, SERA (1999:3-26) noted that hexachlorobenzene could, over time, be transport to water by volitization or runoff.

GLEAMS modeling suggested runoff of hexachlorobenzene into a simulated pond is not likely in areas with annual rainfall less than 10" (SERA 1999:3-26). In a simple modeling of hexachlorobenze movement across a 100' buffer from a treatment area to a pond, SERA (1999:3-27) calculated the proportion running into the water each year as approximately 0.002 of the hexachlorobenzene applied.

Sulfometuron methyl

Overview

With ground application, the limited field monitoring of sulfometuron methyl in the southern US documents sometimes detectable, but low, concentrations of sulfometuron methyl in surface waters. Persistence of sulfometuron methyl in soil depends on soil chemistry and moisture content. Field and laboratory-based soil half-lives are typically one month or less. Although leaching has been documented, low application rates of sulfometuron methyl reduce leaching to shallow soil depths under common soil conditions. Soil application under or near the target plant is the primary mode of treatment.

Information Sources

A US EPA Reregistration Eligibility Decision is not available for sulfometuron methyl and data from only a few forestland water monitoring studies are available. This assessment is based primarily on secondary sources and research recently submitted for publication.

Disposition in Soil

In soil, sulfometuron methyl degrades similarly to many herbicides with microbial activity as a major avenue of decomposition (Extoxnet 1996), although Odell (1999) noted that the initial phase of degradation is hydrolysis, not necessarily in the presence of microorganisms. Sulfometuron methyl does not produce known metabolites of significant environmental concern. Major metabolites of sulfometuron methyl in soil include "methyl 2-[[N-(aminocarbonyl) amino] sulfonyl] benzoate, methyl 2-(aminosulfonyl) benzoate, and saccharin. The latter compounds undergo further microbial degradation to CO_2 and 2 (aminosulfonyl) benzoic acid, respectively" (Anderson and Dulka 1985, cited in Odell 1999).

Persistence

Sulfometuron methyl is described as being "of low to moderate persistence" (Extoxnet 1996) and "moderately persistent" (Cox 1993:32) in soils. Michael (submitted) notes: "Breakdown of sulfometuron methyl through metabolism and by chemical degradative pathways significantly decreases sulfometuron methyl persistence in the environment." And Information Ventures, Inc. (1995) stated "Sulfometuron methyl remains in the soil longer with cool temperature, low soil moisture or alkaline soil pH."

Reported half-lives in soil are typically $\leq$ 1 month and include:

- 5-33 days in clay loam and sandy soils in Mississippi and Florida respectively (Michael and Neary 1993:409)
- 12-15 days at field sites in Missouri, Texas and Illinois, and 25 days in California (Truby et al. 1998, cited in Odell 1999)
- one month in four soils from Delaware, Illinois and Florida (US EPA 1981, cited in Cox 1993:32)
- 33 days (bare ground, aerial application) (Michael submitted)
- 20-28 days (Wauchope et al. 1992, cited in Extoxnet 1996)
- 1 to 3 weeks, depending upon soil type, vegetation cover, and pH (US EPA 1992, Anderson 1981, and Trubey 1991, all cited in Extoxnet 1996)

- "... about 1 month" (1st order half-life) (Anderson and Dulka 1985, cited in SERA 1998:2-2)
- up to 8 weeks under anaerobic soil conditions (US EPA 1992, cited in Extoxnet 1996)
- "... approximately 1 month ... ." (Information Ventures, Inc. 1995)

Nevertheless, sulfometuron methyl may persist at low concentrations in soil for months. In a forestry application, sulfometuron methyl "... was detectable in soil 60 days after application ... " (Michael and Neary 1988, cited in Cox 1993:32). Cox (1993:32) describing results from Anderson and Dulka (1985) listed persistence in soil from locations in Delaware, North Carolina, Oregon, Colorado and Saskatchewan as one year, and Lym and Swenson (1991, cited in SERA 1999:App. 3-1) "detected [sulfometuron methyl] after more than 400 days."

Mobility and Leaching

Sulfometuron-methyl has the potential to leach into ground water. It is relatively soluble in water and has a low organic carbon soil adsorption coefficient (Kollman and Segawa 1995, cited in Odell 1999). This combination indicates potential mobility in soil. The combination of mobility and persistence in soil suggest potential leaching and ground water contamination (Odell 1999). Field observations confirm the mobility and leaching of sulfometuron methyl in some conditions, but not others:

- "Leaching of sulfometuron in agricultural and to a lesser extent forest soils has been described" (Michael submitted).
- "... very little lateral transport at slopes of up to 15% after one year" (Lym and Swenson 1991, cited in SERA 1998:App. 3-1)
- Stone (1993, cited in Michael submitted) observed sulfometuron methyl movement in acid, low base-saturated sandy soils common in forests in Michigan, Wisconsin and Minnesota.
- "... sulfometuron methyl was determined to be relatively immobile in soil (confined to the upper 15 cm of soil) at all test sites [on bare soils in Missouri, Illinois, Texas and California]" (Truby et al. 1998, cited in Odell 1999)

Soil chemistry and application rate can mollify leaching potential of sulfometuron methyl. Information Ventures, Inc. (1995) stated "[I]n acidic soil, sulfometuron methyl has little potential for movement into ground water. However, when applied to water-saturated alkaline soil, considerable movement of sulfometuron methyl may occur." Odell (1999) concurred and added that the typically low rate of application of sulfometuron methyl (e.g., 3-8 oz/acre) "... will reduce the probability of finding it in ground water in detectable concentrations."

Disposition in Water

Persistence

Sulfometuron methyl appears to break down readily and rapidly in water, although Odell (1999) noted "[H]ow much of the compound [sulfometuron methyl] is found in surface water is largely dependent on pH and temperature." "Sulfometuron-methyl ... is rapidly degraded [in water] and does not appear to pose a threat to groundwater. ... In well aerated acidic water, the compound [sulfometuron methyl] is broken down quickly" (Extoxnet 1996). "Reported field half-lives for sulfometuron-methyl in water vary from 1 to 3 days (US EPA 1984 cited in Extoxnet 1996) to 2 months or more" (US EPA 1992 cited in Extoxnet 1996). In monitoring of sulfometuron methyl applied in forested settings in Florida, Neary and Michael (1989) detected measurable

concentrations in samples were collected between 3 and 7 days after application. Sampling, with no detections, continued to 203 days after application.

Surface Water Concentrations

The limited known field monitoring of sulfometuron methyl in forest streams documents low concentrations of sulfometuron methyl from ground applications (Appendix D). No modeling estimates of sulfometuron methyl in forest streams are known. From two Florida forest studies Michael and Neary (1993) reported 5 and 7 µg/l peak sulfometuron methyl concentrations in streams from ground applications of dispersible granules and pellets, respectively. Buffer width at the Florida sites is unknown for one site and 5 m for the second. At the buffered site, measurable concentrations were detected in 10 of 185 stream samples collected after ground application to predominantly sandy soil (Neary and Michael 1989). Maximum sulfometuron methyl stream concentrations from aerial application at three forest sites in Mississippi--23 and 44 µg/l (Michael and Neary 1993) and >49 µg/l (Michael submitted), were higher than for ground application.

Depending upon rainfall amounts, surface runoff of sulfometuron methyl is possible. In agricultural rainfall simulation studies runoff losses ranged from 0.7 to 1.4% of the applied sulfometuron methyl with 12-30 mm rain applied to a sandy loam soil (Wauchope et al. 1992, cited in SERA 1998:4-13) and 0 to 4.2% of 84 mm simulated rainfall in sandy clay loam (Hubbard et al. 1989, cited in SERA 1998:4-13). Summarizing these and other studies, SERA (1998:4-13) concluded "... at least 1% of the applied sulfometuron methyl could run off from the application site to adjoining areas after a moderate rain. In the case of a heavy rain, losses could be much greater and might approach 50% in cases of extremely heavy rain and a steep soil slope." Michael (submitted) notes that the runoff concentrations in the Hubbard et al. and Wauchope et al. agricultural simulation studies are "... 142- and 100-fold (respectively) greater than values reported by Neary and Michael (1989) for natural rainfall on treated forest sites." Many forested areas in the western US receive snowfall as an appreciable percentage of their total annual precipitation. Snowfall typically generates runoff at a lower rate than rainfall of the same amount, and rainfall intensities similar to those cited in the simulated rainfall experiments (e.g., 8.4 cm in 2 hr) probably seldom occur in most western forest and rangelands.

No known field monitoring data exist for the metabolites of sulfometuron in surface water in forested environments.

Groundwater Concentrations

The little known field data on groundwater concentrations of sulfometuron methyl suggest that deep groundwater is not typically contaminated by sulfometuron methyl. In their Florida and Mississippi studies, Michael and Neary (1993:409) reported that sulfometuron-methyl "... was not detected below 30 cm at either site." And Neary and Michael (1989:617) state with respect to monitoring at a Coastal Plain flatwoods location, "Sampling of a shallow ground water aquifer, did not detect any sulfometuron methyl residues for 203 days after herbicide application [by ground sprayer]."

No known field monitoring data exist for the metabolites of sulfometuron methyl in groundwater in forested environments.

Triclopyr

Overview

With establishment of adequate streamside buffers, and absent direct application onto surface waters, triclopyr concentrations in surface waters are typically not detectable or detectable in very low concentrations in forestry applications. Triclopyr appears to be variably persistent in soil with minimal mobility and minimal leaching evident in field studies. Little is known about triclopyr concentrations in ground waters in forested areas although a recent survey of ground waters in primarily agricultural and urban areas did not detect triclopyr at over 2600 sites across the US. Foliar application is the primary mode of treatment.

Information Sources

Both primary and secondary information sources are used in this summary. The primary sources are relatively narrowly focused. The secondary sources address a broader range of environmental fate issues. An important source is US EPA's "Reregistration Eligibility Decision" (USEPA 1998). This document is authoritative. Several articles published after 1998 are also referenced. Results of field monitoring of triclopyr in forest streams in the Sierra Nevada and North Coast ranges of California are included.

Formulations of Triclopyr

Two formulations of triclopyr are used in commercial herbicides. Triclopyr triethylamine salt (TEA) can be a liquid, a granular or pelleted solid, or a wettable powder. In 1998, US EPA identified 24 registered TEA products. Triclopyr butoxyethyl ester (BEE) as a liquid was registered as 12 products in 1998 (USEPA 1998). Three products are commonly used in forestry: Garlon 4 and Pathfinder, both the ester formulation, and Garlon 3A, the amine formulation.

Disposition in Soil

TEA and BEE dissociate in water to triclopyr acid/anion and triethanolamine and triclopyr acid/anion and butoxyethanol respectively. Both triethanolamine and butoxyethanol rapidly dissipate through microbial degradation (Ganapathy 1997). US EPA (1998:51) listed laboratory and field half-lives for terrestrial BEE from two studies as 0.5 and 1.1 days. Triclopyr acid/anion is the predominant compound present in the environment when products containing either triclopyr BEE or triclopyr TEA are used (USEPA 1998:50). The following discussion presumes triclopyr acid/anion (labeled triclopyr), unless otherwise noted, as the chemical of interest in environmental fate assessments.

In soil, the predominant degradation pathway for triclopyr is microbial degradation (Ghassemi et al. 1981, cited in Ganapathy 1997:4) to the major metabolite 3,5,6-trichloro-2-pyridinol (TCP). TCP does not appear to form in a 1:1 ratio to the amount of triclopyr applied; US EPA (1998:54) reported maximum TCP concentrations of 26% of the initial triclopyr acid applied under aerobic soil metabolism conditions. A second metabolite, 3,5,6-trichloro-2-methoxypyridine (TMP) was produced at about one-ninth the rate of TCP in one laboratory study (Ganapathy 1997, citing Lee et al. 1986). Both TCP and TMP eventually convert to CO_2 (Ghassemi et al. 1981, cited by Ganapathy 1997).

Persistence

Triclopyr appears to be variably persistent in soils, with some sources describing it as persistent and other as not persistent. US EPA (1998:50) described triclopyr as "somewhat persistent,"

although "... triclopyr residues did not persist in field dissipation studies." In a lysimeter study at the forested Savannah River Site in Georgia, "[T]riclopyr residues were not persistent and remained below 6 ppb during the study [over 3 years]. The only occurrence of triclopyr in the deep lysimeters [84-109 cm] was at 0.3 ppb 79 days following the first spot application" (Bush 2001). Ghassemi et al. (1981, cited in Ganapathy 1997:4) stated "Since triclopyr is rapidly degraded by soil microorganisms, there is not enough residue left to injure plants the next growing season." In a differing opinion, Cox (2000:17, citing Norris et al. 1987 and US EPA 1978) stated that triclopyr persisted for a year in a field study in western Oregon after treatment with the amine salt and over a year in another field study.

Soil half-lives reported for triclopyr generally range between one and three months and include:

- 46, 45 and 40 days (all averages), and 14 days (selected Canadian forest soils) (SERA 1999:2-3, citing four sources)
- 46 days (Information Ventures, Inc. 1995)
- 10-100 days Cox (2000, attributed to US EPA 1998)
- 96 $\pm$ 9.9 days, combination of exposed (stripped of vegetation) and naturally-vegetated forest soil (Cryer et al. 1993, cited in Ganapathy 1997)
- 26 and 85 days, respectively, for total triclopyr (BEE plus triclopyr acid) and TCP (US EPA 1998:52)

Soil half-lives for triethanolamine and butoxyethanol are relatively short. US EPA (1998:52,55) reported half-lives of 5.6-13.7 days for triethanolamine in aerobic soil and 4 and 10 days for butoxyethanol in sandy loam and silt loam respectively.

Mobility and Leaching

Although triclopyr's soil adsorption coefficient is similar in magnitude to that of mobile herbicides, many studies indicate that operationally triclopyr experiences minimal mobility and leaching. Ganapathy (1997) noted that triclopyr's sorption to soil increases over time (thereby decreasing its leaching potential) and hypothesized this may be the cause of the differing results.

In process-based simulations using a root zone model for pine forest conditions in the Canary Islands, triclopyr was characterized as being a potential leacher (Diaz and Loague 2001). US EPA (1998:57) described triclopyr as "very mobile"--based on adsorption/desorption studies of sand, sandy loam, silt loam, and clay soils, and as having "... the potential to leach to ground water."

On the other hand, numerous sources attribute low mobility and leaching potential to triclopyr. Information Ventures, Inc. (1995) stated "[T]riclopyr should not be a leaching problem under normal conditions since it binds to clay and organic matter in soil" and Bush (2001), in concurrent lysimeter monitoring of four herbicides, determined the "... relative potentials of herbicides to move into shallow groundwater ..." as greater for all three other herbicides (picloram, metsulfuron methyl and clopyralid) than triclopyr. In a different report, Bush et al. (1995:115) reiterated that triclopyr—and imazapyr--were not as mobile or persistent in shallow wells as picloram or hexazinone. In a forestry field study "... triclopyr remained mainly in the top 6 inches of soil ... [and] ... only a fraction of the percent applied was detected at soil intervals below 24 inches at six months after treatment (Cryer et al. 1993, cited in Ganapathy 1997). SERA (1999:4-12) noted that neither BEE nor triclopyr acid is very mobile in loamy soil. Last, Ganapathy (1997, citing Newton et al. 1990)--describing results of a southwest Oregon forestry

field study--stated "... triclopyr was practically immobile in soil-water and therefore would only move a short distance in forest subsurface flow."

Disposition in Water

Persistence

Triclopyr is not anticipated to persist in surface water, although it may under flood conditions. The primary degradation pathway for triclopyr in water is photo-degradation (Ganapathy 1997), with half-lives listed as less than 1 day in sterile solutions, approximately 1 day in natural water in laboratory studies, and 0.5-3.5 days in Lake Seminole, Georgia (US EPA 1998:51). Similar half-lives were recorded for triclopyr (3.7-4.7 days) and TCP (4.2-7.9 days) for Lake Minnetonka, Minnesota (Getsinger et al. 2000) and ponds in California, Missouri and Texas (5.9 -7.5 days for triclopyr and 4-8.8 days for TCP) (Petty et al. 2001). Triethanolamine is stable (half-life 14-18 days) in aerobic aqueous conditions but can persist much longer (half-life > 2 years) under anaerobic aquatic conditions (US EPA 1998:52).

"Triclopyr and TCP do not adsorb to soil and sediment particles, and may be transported in surface runoff waters. Although triclopyr is not predicted to persist in surface water, information from two aquatic field dissipation studies conducted on rice indicated that following application of triclopyr, TCP could persist in flood waters" (US EPA 1998:53). US EPA (1998:42) labeled TCP as persistent in aquatic environments.

Surface Water Concentrations and Geographical Scope

With establishment of adequate streamside buffers, and absent direct application onto surface waters, triclopyr concentrations in surface waters are typically not detectable in forestry applications, and "... applications of triclopyr could be made without harm to nearby streams" (Ganapathy 1997:14). Appendix D lists maximum triclopyr surface water concentrations reported in three field studies in the southern US from ground treatments adjacent to buffered streams. Two studies in S. Carolina (Bush et al. 1995) found no detectable triclopyr. Although 2 mg/l peak concentration of triclopyr was measured in the third study, the buffer, at 5 m width, may have been only marginally effective. Data from water quality monitoring in Sierra Nevada and North Coast forestland streams in California confirm the extremely low likelihood of detectable concentrations of ground-applied triclopyr in adequately buffered streams (Appendix D). In analyzing these data, Bakke (2001) noted—

- "The few positive detections in non-accidental or erroneous applications in water monitoring are all at low levels (highest 2.4 ppb)."
- "The detection that resulted in the highest level of triclopyr (82 ppb) was the result of an absence of an untreated buffer on an ephemeral stream."
- "It would appear from these monitoring data that untreated streamside buffers of greater than 15 feet in width reduce risk of water contamination to near zero."

US EPA models "estimated environmental concentrations" of pesticides as a "coarse screen" using the GENEEC (Generic Expected Environmental Concentration Program) model. GENEEC is designed to mimic a PRZM-EXAMS simulation. In this application, GENEEC simulates runoff from a 10-ha field into a 1-ha, 2-m deep water body, with no buffer zone between the field and water body. There is no soil incorporation, and a single application at maximum use rate for a site is specified. Input values and other caveats for interpreting GENEEC model results are described in US EPA documentation (e.g., 1998:66-68). Results of GENEEC simulations for TEA and "worse-case" conditions for BEE are shown in Tables E-2, E-3 and E-4.

Table E-2. Estimated Environmental Concentrations (EEC) for triclopyr TEA, Ground Application

Rate (labs ae[1]/acre)	Peak EEC (ppb)	Day 21 EEC (ppb)	Day 56 EEC (ppb)
1.0	30	25	19
3.2	95	80	61
9.0	270	227	173
12.1	364	305	233

[1] acid equivalent

Table E-3. Estimated Environmental Concentrations (EEC) for triclopyr TEA, Aerial Application

Rate (labs ae/acre)	Peak EEC (ppb)	Day 21 EEC (ppb)	Day 56 EEC (ppb)
6.0	186	156	119

Table E-4. Estimated Environmental Concentrations (EEC) for triclopyr BEE

Ground Application		Aerial Application	
Rate (labs ae/acre)	Peak EEC (ppb)	Rate (labs ae/A)	Peak EEC (ppb)
1.0	19	1.5	30
3.0	57	8.0	160
8.0	152		
12.0	228		

Ground Water Concentrations

Little is known about triclopyr concentrations in ground water in forested areas. US EPA (1998:63) stated: "To date, there has been limited monitoring for triclopyr in ground water in the United States." Nevertheless, TCP "... has the potential to degrade groundwater (US EPA 1998:53)" and "[T]he acid and its degradate TCP are of concern in the ground water assessment (US EPA 1998:62)." Hoheisel et al. (1992, cited in US EPA (1998:63) noted five detections of triclopyr residues from 379 wells sampled in four states. The maximum reported concentration was 0.58 ppb. It is not known if any of these wells were located in forested environments. In their survey of 20 mostly agricultural and urban study units across the nation, the USGS (2000) did not detect triclopyr in ground water at any of over 2600 individual sites.

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Appendix G. Monitoring Protocols

Many research studies and operational monitoring projects have documented herbicide concentrations in surface waters. A variety of sampling schedules and related procedures have been used. The examples described below are best considered "case studies" of field procedures developed specifically for effectiveness monitoring, rather than research studies. Several of the examples advocate additional components in the monitoring scheme, like coordination, investigation of citizen complaints, and partnership building with other organizations that are not described here.

These examples focus on water column sampling. Three examples are given, from research in Washington and the State of Oregon and operational monitoring by the Pacific Southwest Region of the USDA Forest Service. One bioassessment example was found, Jeff Vowell's before-after approach used in Florida (Vowell in press). Details of the bioassessment approach were not given in the literature reviewed.

Rashin and Graber (1993)

Rashin and Graber (1993) applied water column sampling protocols developed in Oregon (Oregon Department of Forestry 1989, cited in Rashin and Graber 1993) and Washington (Washington Department of Natural Resources 1990, cited in Rashin and Graber 1993) and recommended a modified version of a composite of these two protocols. The primary modification is the inclusion of more intensive sampling. This protocol is based on observations of aerial application of glyphosate (Accord), 2,40D (Weedon LV4), triclopyr (Garlon 4) and imazapyr (Arsenal). Rashin and Graber (1993) noted that the Oregon and Washington protocols differed in their timing of sample collection; Washington based sample collection time on the beginning of spraying whereas Oregon included allowance for time-of-travel of the chemical in streams. Depending upon the size of spray units, these timing differences apparently produced different detectabilities of the first spike of pesticide in stream water. Rashin and Graber (1993) therefore used different bases for timing of sample collection for large and small spray units.

Long-term sampling is not incorporated into the protocol; the intent is to characterize peak concentrations and estimate 24-hour average levels in a cost-effective manner. Sample collection focuses on the initial four hours following treatment partly because "... except in cases where runoff occurs very soon after spraying, the highest stream concentrations occur within the first four hours" (Rashin and Graber 1993:73). To keep costs down, automatic pump samplers are not advocated and "mandatory" sample collections end 24 hours after spraying.

Static measurements required include stream channel length within the spray unit and distance from the downstream boundary of the spray unit to the sampling site. Streamflow (discharge) measurements are desirable, within 50 m downstream from the sampling site. The discharge measurements quantify flow velocity for a time-of-travel determination. Time-of-travel conditions the scheduling of the first post-treatment sample collection. Grab samples are collected before spraying begins for small (< 20

hectare) and larger (> 20 hectare) units, and ½, 1, 2, 4, 6 and 24 hours after the completion of spraying—for small units—or after the start of spraying plus time-of travel—for larger units. Optional samples collected at ¼, 3 and 48 hours can provide greater data resolution and data on pesticide persistence. A field replicate sample is also collected and a sample from the first runoff-producing rain event, particularly if it occurs within 72 hours after treatment, is recommended.

Rashin and Graber (1993, Appendix G) provided further information on sample collection siting, QA/QC procedures, calculation of the 24-hour average concentration, and an operator questionnaire and sampling schedule forms.

Oregon Department of Forestry

In 1997 the Oregon Department of Forestry (ODF) published a monitoring protocol for testing the effectiveness of BMPs for protecting water quality from aerial applications of forest pesticides (ODF 1997). Although the source publication (ODF 1997) states "Effectiveness monitoring will consist of water quality and aquatic insect sampling ... " the publication describes water column sampling exclusively.

Surface water monitoring would occur in autumn and spring, depending upon the use scheduling of herbicides of interest. Sites would be selected predominantly from counties with the greatest rate of treatment. Human health, fish and invertebrate toxicity target criteria formulated as 24-hour average concentrations are the "standard" for comparison to monitoring results (ODF 1997).

The ODF approach is similar to the Rashin and Graber (1993) approach. Grab samples are scheduled for collection within 24 hours before application, and at ¼, 2, 4, 8 and 24 hours after treatment, but incorporating a time-of-travel adjustment. Additional samples would be collected at a subset of sites if runoff occurred with 72 hours after treatment. Collection sites would be approximately 60 m downstream of the treatment unit boundary.

ODF (1997) provides further information on QA/QC procedures, calculation of the 24-hour average concentration, and operator questionnaire and sampling forms.

USDA Forest Service

The Pacific Southwest Region of the USDA Forest Service produced a draft herbicide water monitoring protocol aimed primarily toward reforestation projects (Frazier and Carlson 1995). This procedure acknowledges the up-front need to identify beneficial uses of water in the project area and developed site-specific monitoring criteria in response to standards associated with the relevant beneficial uses. This protocol incorporates pre-treatment, treatment and post-treatment observations and sampling of surface water, groundwater and streambed sediment.

The pre-treatment phase focuses on water sample collection. A primary aim of the monitoring during herbicide application is to ensure the functional integrity of streamside buffers strips. Spray cards, fluorometric measurements or colorant added to the herbicide mix are recommended to aid in detection of herbicide drift. If the monitoring shows that herbicide drift or direct spray is entering surface water, the operation would be stopped, corrective action taken and water samples would be collected to quantify the magnitude of contamination. Post-treatment water sample are collected during the first significant storm after application that produces runoff. Sample collection during subsequent storms is recommended if previous storms produced sufficient herbicide residue to warrant concern. Sampling frequency is also based on chemical mobility, persistence and season of application. Contrary to the Washington and Oregon protocols, Frazier and Carlson (1995) do not specify specific sample collection scheduling.

Frazier and Carlson (1995) address sampling station selection, sampling handling and analysis and QA/QC issues for surface water, ground water and sediment sample collection.

A variant of this protocol was used on the Stanislaus Naitonal Forest as a "nested" approach sampling at site (15-80 hectare) and watershed (800-3,200 hectare) scales. The purpose of the site-scale monitoring was to attempt to determine maximum potential herbicide concentrations in water, particularly because of limited experience and knowledge of the fate of hexazinone in local watersheds. Outlets at the mouths of watersheds were sampled to quantify herbicide concentration leaving the project area and contributing to downstream flow (USDA Forest Service 2003).

Discussion

The Washington and Oregon protocols are very similar. They both focus on water chemistry sampling during and soon after herbicide treatment. The USDA Forest Service approach bypasses routine water column sampling during treatment and more strongly directs sample collection during post-treatment runoff-producing events. Reasons for these differences are not completely known although they may stem from differing perspectives or philosophies of monitoring. The Washington and Oregon approaches tie directly into 48-hr toxicology criteria for aquatic biota. The Forest Service approach is more open-ended in that differing beneficial uses of water may prompt comparison of monitoring results to different water quality criteria (this is not to say that the Washington and Oregon protocols are exclusively locked in to 48-hr aquatic life criteria). The Forest Service and Washington/Oregon approaches complement each other in providing options for both short and longer-term determination of potential herbicide effects on surface water quality.

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